Best Practices
Guide

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Best Practices Guide

Microwave Radio Systems

harris
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Best Practices Guide

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Rev 005a captures rebranding for Harris Stratex Networks Inc.

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About This Manual

About This Manual introduces the Harris Stratex Networks Best Practices Guide. Refer to the following topics:

Welcome to Best Practices

This manual describes standard practices and procedures common to all Harris Stratex Networks radio systems, including:

- Recommended safety standards
- Minimum standards to ensure reliable network operation
- Acceptable standards dictated by the Harris Stratex Networks Warranty policy

It also provides a wealth of information on planning and installation practices, systems operation, testing, troubleshooting and technical background.

While Best Practices is a Harris Stratex Networks' publication, it is a generic document. The content is directly applicable to Harris Stratex Networks' radios, but as an industry guide is considered to be generally applicable to all split-mount and indoor digital microwave radio systems.

Purpose

Best Practices is a guide for planning, installing, commissioning, and maintaining microwave links.

Following Best Practices will help maximize the quality of your installation process and subsequent operational performance. Some of the benefits that can be expected are:

- Installation and commissioning processes are carried out more efficiently
- By removing installation-related causes of failure, equipment MTBF's should be as specified
- Much lower overall failure rates leading to lower maintenance costs, especially in the areas of fault response and outages
- Lower shipping and other logistical costs associated with returning equipment for repair
- Overall, fewer outages means a happier user experience and lower operational costs
- By following a Networks’ Best Practices customers qualify for our 27 month extended warranty

Our goal is to have Harris Stratex Networks’ equipment installed to a consistent high standard around the world.

For existing installations, results have shown that those that have been upgraded to meet these practices have experienced much improved MTBF's.

Intended Audience

This manual is intended for personnel responsible for planning, installing and maintaining Harris Stratex Networks radio systems.

Content Ownership

The departments responsible for the content in this guide are Installation Practices, Field Services, and Field Quality. Direct suggestions and comments to:

- Director of Installation Practices
- Director of Field Services

Guide Overview

Chapter 1 covers safety of personnel and discusses general hazards.

Chapter 2 discusses planning guidelines.

Chapters 3 through 9 provide guidelines for installing and commissioning microwave radio links, including hints, tips, and background information. Both split-mount and all-indoor installations are addressed.

Chapter 10 provides guidance on troubleshooting.

Appendix A introduces an Excel based formset for pre-installation checks, including site survey, lightning protection and grounding survey, and a pre-installation checklist.

Appendix B introduces an Excel based formset for installation and commissioning. It includes forms and checklists for an installation datapack, racking, circuit connections, commissioning, inspection, acceptance, and remedial action.

Appendix C provides a VSWR reference chart.

Appendix D provides guidance on typical fault scenarios with a description, probable cause, and recommended actions for commonly encountered path-related faults.

The guidelines are generic in their application.

These guidelines are designed to support instructions provided by an equipment manufacturer for specific models of link equipment. If there are differences between these guidelines and those of the manufacturer, follow the manufacturer's instructions, or check with the manufacturer.

Figure 1. Remote hilltop GSM and radio repeater site

Organization

This guide is organized into the following chapters and appendices:

Chapter 1. Safety

Provides safety information and guidelines for installing and maintaining Harris Stratex Networks radio systems.

Chapter 2. Planning

Provides planning guidelines for the installation of radio links subsequent to the site survey stage.

Chapter 3. Antenna Selection, Installation, and Alignment

Describes point-to-point microwave antennas available for frequency bands 300 MHz to 38 GHz, their installation, initial alignment, wind loading, and environmental protection.

Chapter 4. Split-Mount Radios - ODU and Cable Installation

Addresses split-mount-specific installation guidelines for an ODU and IDU/ODU cable, including running, fixing, grounding, connectors, and lightning surge suppression.

Chapter 5. All Indoor Radios - Feeder Selection and Installation

Provides guidelines on the selection and installation of waveguide or coaxial cable for all-indoor radios, including running, fixing, grounding, and connectors.

Chapter 6. Lightning Protection and Site Grounding Requirements

Provides information and recommendations on lightning surge suppression devices, and site and equipment grounding.

Chapter 7. Indoor Equipment Installation

Provides installation guidelines on rack-mounted equipment for all-indoor and split-mount radios.

Chapter 8. Commissioning

Describes typical commissioning procedures and tests.

Chapter 9. Troubleshooting

Provides guidelines for troubleshooting point-to-point digital microwave radio links.

Appendix A. Site Survey Formset

Provides checklists for use during a site survey to help ascertain the readiness of a site for a new installation. Includes checks of site grounding and lightning protection.

Appendix B. Installation and Commissioning Formset

Contains procedures, forms and a checklist for use during installation, commissioning and link acceptance processes.

Appendix C. Voltage Standing Wave Ratio (VSWR) Reference Chart

Describes the relationship between VSWR, Return-Loss, and Power.

Appendix D. Typical Fault Scenarios

Provides fault descriptions, probable causes, and recommended actions for a range of typical path related faults.

Referenced Material

The following material was referred to during the writing of this guide:

- Andrew Corporation Catalog 38
- Radio Waves Product Catalog 2004
- Microwave Radio and Transmission Design Guide by Trevor Manning. An Artech House publication.
- Various publications from PolyPhaser Corporation
- Various ETSI documents
- FCC document ‘Part 101’

Conventions and Terminology

Graphical Cues

The following icons function as graphical cues used to characterize particular types of associated supporting information.

A *caution* icon denotes important information pertaining to damage to equipment, loss of data, or corruption of files.

A *warning* icon denotes danger to life and/or limb.

A *note* icon denotes additional information you may require to complete the procedure or understand the function.

Use of Bold Font

- **Bold font** may be used for the names of on-screen elements such as; fields, buttons, and drop-down selection lists, tabs, keywords, commands and for keys on the keyboard.
- **Bold font** may also used to indicate commands that the user needs to type in.

Use of Italic Font

Throughout this manual italic font is used to emphasize words and phrases, to introduce new terms, and for the titles of printed publications.

Common Terminology

- **Click**—Point the mouse pointer at the item you want to select, then quickly press and release the left mouse button.
- **Right-Click**—Point the mouse pointer at the item you want to select, then quickly press and release the right mouse button.

Chapter 1. Safety

This chapter provides safety information and guidelines for installing and maintaining Harris Stratex Networks (HSX) radio systems. Refer to:

Overview

This chapter covers the following topics:

Operator Safety

- Radio Frequency and Microwave Safety
- Electrical Hazards
- Chemical Hazards
- Laser and Fiber Optic Cable Hazards
- Hoisting and Rigging Safety
- General Site Safety

General Hazards

- Electrostatic Discharge Protection
- Maximum and Minimum Ambient Temperature
- Airflow Requirements
- Circuit Overloading
- Power Supply Connection
- Equipment Ground Connections
- Fiber Optic Cables
- Lightning Surge Suppressors
- Mechanical Loading
- Restricted Access

Operator Safety

This section sets out health and safety issues for personnel working with and around microwave radio equipment.

Radio Frequency and Microwave Safety

Radio frequency (RF) and microwave (µW) electromagnetic radiation spans the frequency range 3 kHz to 300 GHz (RF between 3 MHz and 300 MHz, µW between 300 MHz and 300 GHz).

RF/µW radiation is non-ionizing in that there is insufficient energy (less than 10 eV) to ionize biologically important atoms, so the primary health effects of RF/µW energy are considered to be thermal.

The absorption of RF/µW energy varies with frequency. Microwave frequencies produce a skin effect—you can literally sense your skin starting to feel warm. RF radiation, however, may penetrate the body and be absorbed in deep body organs without any warning signs.

RF/µW Safety Guidelines

Since the long-term effects of low-level microwave radiation upon the human body are not completely understood at this time, Harris Stratex Networks' recommendations for maximum safety include the following:

- Do not operate microwave equipment without first having proper training or knowledge of microwave radio operation.
- Do not operate the microwave equipment without an appropriate antenna port termination, or antenna.
- Check to ensure that the area around the antenna is clear of personnel prior to turning the transmitter on.
- Do not look into or stand in front of an antenna.
- Do not swing or aim an antenna at nearby persons while the equipment is operating.
- Do not look into an open waveguide port while the equipment is operating as irreversible damage to the eye(s) may result. The waveguide directs microwave energy between the transmitter and the antenna and since the cross-sectional area of a waveguide is small, the power density is high and can be in excess of recommended safety levels.
    - Always exercise caution when working with open waveguides.
    - Turn off the power before working with waveguide connections.
- Where a structure or rooftop has existing antennas installed, do not proceed with an installation without first determining the RF/µW exposure risk. If necessary ask the structure/rooftop owner or operator. Where necessary have the relevant transmitters turned off or wear a protective suit for the duration of the installation.

RF Safety Standards

Refer to local safety standards for RF safety compliance requirements. Refer to the following safety standards for more information on RF emissions and microwave radiation safety:

- ANSI, 1982, “American National Standard-Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 300 kHz to 100 GHz.” Report ANSI C95.1 1982, American National Standard Institute, New York.
- ANSI C95.5 - 1981, “American National Standard: Recommended Practice for the Measurement of Hazardous Electromagnetic Fields - RF and Microwave.”
- AS 2772.2 - 1988, “Australian Standard: Radio frequency radiation, Part 2 - Principles and method of measurement 300 kHz to 100 GHz.”
- European Commission - Non Ionizing radiation Sources, exposure and health effects doc CEC/V/F/1/LUX/35/95 - Luxembourg 1995.
- EUROPEAN PRESTANDARD, ENV 50166 - 1, “Human exposure to electromagnetic fields - Low-frequency (0 Hz to 10 kHz).” CENELEC, Ref. No. ENV 50166-1: 1995 (January 1995).
- EUROPEAN PRESTANDARD, ENV 50166 - 2, “Human exposure to electromagnetic fields - High frequency (10 kHz to 300 GHz).” CENELEC, Ref. No. ENV 50166-2: 1995 (January 1995).
- IEEE Std. C95.3-1991 - IEEE Recommended Practice for the measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave - IEEE, August 21, 1992 New York, USA.
- IEEE - ANSI (1992) - IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz - (Standard IEEE C95.1 - 1991. Revision of ANSI C95.1 - 1982) New York, NY, Institute of Electrical and Electronics Engineers.
- IEEE - Entity Position Statement (1992), “Human Exposure to Radio frequency Fields from Portable and Mobile Telephones and Other Communication Devices,” IEEE United States Activities Board, December 2, 1992.

Electrical Hazards

All HSX radio systems comply with global product standards for Safety, Extra Low Voltage (SELV) rated equipment. They are designed to operate from a nominal 48Vdc supply where the maximum voltage is not to exceed 60 Vdc. Accordingly, hazardous voltages are not used in the operation of HSX radio systems.

However, the power supply providing the nominal 48Vdc supply will normally be AC mains powered, and test equipment used in conjunction with HSX products may also be AC mains powered. Similarly, the rack into which the HSX products are installed may well contain other AC mains powered equipment. Voltages above 60Vac or dc can shock and kill.

Electrical Safety Guidelines

To avoid electrical shock, follow these recommendations:

- Check for possible hazards in the work area, such as moist floors, ungrounded power extension cords, and missing or doubtful safety grounds.
- Do not work alone if potentially hazardous conditions exist in your work space.
- Never assume that power is disconnected from a circuit. Always check the circuit before starting work.
- Locate the emergency power-off switch for the room in which you are working so that if an electrical accident occurs, you can quickly turn off the power.
- Ensure equipment is correctly protected with a fuse or circuit breaker.
- The power supply battery can have a short-circuit current capacity of many hundreds of amps. If short circuited before the fuse or circuit breaker, the resultant flashover can cause serious burn injuries. Ensure battery terminals and leads are suitably shielded against accidental short circuit.
- Install equipment in compliance with the following international or national electrical codes:
  - International Electromechanical Commission (IEC) 60364, Part 1 through Part 7.
  - United States—National Fire Protection Association (NFPA70), United States National Electrical Code.
  - Canada—Canadian Electrical Code, Part 1, CSA C22.1.
  - Codes that apply to your country.
- Complete the entire installation and check the grounding, including connected peripheral equipment, *before* applying power to the radio system.
- Disconnect power to the radio system before replacing equipment, except as may be specified in the relevant equipment manual for powered-up swap-out, or installation of field-replaceable units.

Chemical Hazards

No hazardous materials are used in the construction of HSX radios and multiplexers. No special handling or disposal procedures are required, except that disposal must be as solid waste and not by burning or shredding.

Some HSX products include a Lithium Manganese battery. Replacement should only be performed by HSX service personnel, and spent batteries must be discarded as solid waste.

Some local authorities may have special disposal requirements for batteries. These requirements must be followed.

For other manufacturer’s equipment, check their data sheets and instructions.

Chemical Hazards Guidelines

Chemical hazards may be present in your work area from other sources, such as battery acid, diesel fuel, cleaning agents, and asbestos building insulation.

General safety guidelines when handling hazardous materials include the following:

- Refer to the Material Safety Data Sheets (MSDS) for the chemicals you use.
- Wear protective clothing, eye wear, gloves, face masks, or respirators as required.
- Work in a well-ventilated area.
- Avoid inhalation of smoke or fumes produced when material is heated.
- Do not smoke near any potentially flammable products.
- Do not wear oil-contaminated clothing.
- After handling hazardous material, wash hands thoroughly with soap and water.

Laser and Fiber Optic Cable Hazards

Laser products are subject to international and US federal regulations and practices. IEC60825–1 and 21CFR1040.10 require manufacturers to certify each laser product as Class I, II, III, or IV, depending on the characteristics of the laser radiation emitted. In terms of health and safety, Class I products present the least eye hazard, while Class IV products present the greatest hazard. A label specifying the Class used should be placed on all devices equipped with a laser transmitter.

Class I laser products provide no danger to personnel from the laser transmitter when the system is in its operating configuration. All HSX radios and multiplexers equipped with laser transmitters use Class 1 devices.

Other transmission products or test equipment used in conjunction with HSX products may have laser transmitters of Class II or higher. While it is unlikely that Class IIIb and Class IV lasers will be encountered in telecommunications installations, should a label identify either, take extra care to avoid exposure as they can cause serious injury.

Laser and Fiber Optic Cable Safety Guidelines

When working with optical fibers, observe the following guidelines to minimize the potential for injury:

- Until checked and confirmed otherwise, regard all laser ports including unterminated fiber cables as ‘live’.

WARNING

Laser light within the infra-red or ultra-violet spectrum is invisible to the eye.

- Avoid direct exposure to fiber cable ends or open optical connectors in the laser signal path.
- Do not look into unterminated optical ports or fibers that connect to unknown sources. If visual inspection is required:
  - For optical ports, ensure the source equipment or its laser transmitter is turned off.
  - For fiber cable, disconnect the far end.
- Follow the manufacturer's instructions when using an optical test set. Incorrect calibration or control settings could result in hazardous levels of radiation if directed towards the eye.
- Protect/cover unconnected optical fiber connectors with dust caps.
- Handle optical fibers with care. Do not attempt to bend them beyond their minimum bend radius.

- Place all optical fiber cuttings and bare fiber scraps in a suitable container for safe disposal. A bare fiber is a fiber that has had the primary coating removed, exposing the fiber's glass surface. These scraps are generated when splicing or terminating fiber during the cleaving process. Fibers and fiber scraps can easily penetrate the skin and eyes, causing a micro-injury that is difficult to handle.

Hoisting and Rigging Safety

Hoisting and rigging activities can result in accidents involving significant property damage, serious injuries, or death. Therefore, these activities must be executed with attention to safety.

Refer to the applicable country regulations for detailed requirements and guidelines.

Harris Stratex Networks’ Requirements

The following guidelines are to be followed by HSX-approved engineering and installation subcontractors. The subcontractor’s quality procedures and safe working practices or any regulatory requirements in the country of installation must also be followed.

- Operators and riggers must be properly trained and familiar with country regulations and requirements.
- Hoisting and rigging equipment must be approved to the appropriate country standard. In some countries certificates need to be available for inspection upon request.
- Hoisting and rigging activities must be carefully planned, and executed according to plan.
- Hoisting and rigging equipment must be checked prior to the lift.
- Hoisting and rigging equipment must not be used to lift personnel.
- Ensure safety harnesses are correctly worn and used at all times when climbing.
- Ensure hard hats are worn by all personnel working on and around the tower/structure.
- Where appropriate, deploy warning signs such as “Danger Men Working Overhead” and “Hard Hat Area” and close off the working area with cones or rope.

Climbing Certificates

Follow the climbing regulations of the country, which may require riggers and other tower-climbing personnel to have an approved climbing certificate.

HSX requires all riggers and tower-climbing personnel (including contractors and subcontractors) to have an approved climbing certificate. A copy of the certificate should be available for on-site inspection.

HSX further recommends that if a contracted rigger does not posses such a certificate then that person:

- Cannot be classed as a rigger
- Cannot be permitted to climb
- Cannot be employed as the safety person for an approved rigger unless there is a second rigger in the vicinity with whom permanent radio or telephone contact can be maintained.

Permit To Climb

Follow the country's regulations to obtain permission to climb. Such permission may not be granted if the site or structure owner or operator, or local authority, states that a structure is unsafe to climb.

Where the climbing activities are monitored by HSX, if the customer or a representative of the site owner, or other authority indicates that it is not safe to climb, no rigging will take place unless a senior rigger or structural engineer certifies that it is safe to climb.

General Site Safety

- Watch for protrusions or sharp or slippery surfaces that may catch or otherwise cause injury. Where possible, cover or restrict access to such areas.
- In a new installation ensure the placement of equipment does not restrict access to it and to other equipment.
- Ensure racks are securely anchored to the floor, and if necessary top-braced. Check to ensure that the additional loading of new equipment into a rack does not cause any reduction in mechanical stability of the rack.

Site Security

Ensure that the site is secure.

- Check for any signs of physical damage or attempted entry on arrival at site.
- On departure, check that doors, shutters, and gates are locked, access ladders removed or locked, and any site alarm activated.
- Notify the operations center on arrival, and on departure.

General Hazards

This section describes protection and safety issues for microwave radio and associated equipment.

Electrostatic Discharge Protection

Electrostatic Discharge (ESD), also known as static electricity, is the sudden transfer of electricity between objects at different potentials. Static charges can cause damage to sensitive electronic components during installation and servicing. Your body can easily pick up a static charge, which can discharge to components or assemblies when touched.

ESD can cause immediate terminal equipment failure but can also cause latent damage, which while showing no immediate or obvious effect, may lead to premature failure.

CAUTION

Personnel and equipment must be properly grounded when ESD sensitive assemblies are handled.

ESD Handling Guidelines

To prevent ESD damage, follow these guidelines:

- Assume that all components, PCBs, and assemblies within a closed electronic housing are sensitive to ESD.
- Handle ESD-sensitive items only when you are properly grounded at a static-safe work area or when connected via a skin-contact ESD grounding strap to a ground on the equipment.
- Restrict handling of ESD-sensitive PCBs and sub-assemblies. Where practical handle assemblies via a front panel or the edges of a PCB.
- Store and transport ESD-sensitive items in static-shielding bags or containers.
- Ensure these handling procedures are maintained during the process of swap out/in of ESD-sensitive assemblies from/to their ESD protecting transport bags or containers.

Maximum and Minimum Ambient Temperature

Ensure compliance with the maximum ambient temperature (Tmra), and minimum temperature specifications for the installed equipment. Equipment performance cannot be guaranteed where ambient temperatures are outside specification.

- To maximize long term component reliability, ambient temperature limits must not be exceeded. Excessive heat is the number one cause of premature equipment aging and failure.
- At very low temperatures the equipment may not start, or may take considerable time to start up.

ODU Temperature Considerations

ODUs are normally specified for a maximum ambient temperature of 50° or 55° C. This is the maximum specified air temperature in *shaded* situations. Solar gain can raise the internal ODU temperatures by 10° Celsius or more, and in equatorial regions especially where ambients can be in excess of 40 C, over-heating may occur. In such environments the ODU should be protected with a sun shield.

Rack-mount Temperature Considerations

If equipment is installed in a closed or multi-unit rack assembly, the operating ambient temperature of the rack environment may be greater than room ambient. The maximum ambient temperature (Tmra) specified applies to the immediate operating environment of the equipment, which if installed in a rack, is the ambient applying within the rack.

> Excessive heat is the number one cause of premature equipment aging and failure. Where possible avoid operating equipment at or near its maximum specified ambient.

Airflow Requirements

Rack installations must be made such that any airflow required for safe and correct operation of equipment is not compromised. Check the manufacturer's installation manual for airflow requirements.

Circuit Overloading

Where an existing DC power supply is to be used for a new radio installation, check the supply has sufficient spare capacity to do the job. Also check that any circuit protection devices and intermediate dc supply wiring will not be overloaded.

Power Supply Connection

Most HSX radios require a -48 Vdc, +ve grounded supply, where the +ve pin within the radio dc connector is fastened directly to the chassis. Such radios must be supplied from a -48 Vdc power supply which has a +ve earth (the power supply earth conductor is the +ve supply to the radio).

- There must be no switching or disconnecting devices in the earth conductor between the dc power supply and the connection to the radio.
- The radio should be located in the same immediate area (same or adjacent racks/ cabinets), as any other equipment that is connected to the same earthed conductor of the same dc supply circuit.
- The power supply should be located in the same premises as the radio system.

Equipment Ground Connections

Reliable grounding of radio equipment must be maintained. Refer to product installation manuals for product-specific grounding instructions. Such instructions should provide details for grounding an ODU, ODU/IDU cable, lightning surge suppressor, and indoor units. For general lightning protection and site grounding requirements, refer to Chapter 6.

Fiber Optic Cables

- Handle optical fibers with care. Keep them in a safe location prior to installation.
- Do not attempt to bend them beyond their minimum bend radius.
- Ensure they are correctly secured and protected from accidental strain once installed.
- Protect/cover unconnected optical fiber connectors with dust caps.

Lightning Surge Suppressors

All HSX radios must be fitted with the specified lightning surge suppressor(s) to avoid voiding the warranty.

Refer to the product manuals for details of suppressor types required and their installation.

For general lightning surge suppressor installation and cause and effect data, refer to Chapter 6.

Mechanical Loading

- When installing the indoor unit in a rack, ensure the rack is securely anchored to the floor and top-braced if necessary.
- Ensure that the additional loading of new installations will not cause any reduction in mechanical stability of the rack.

Extra attention to rack anchoring and fastening will be needed in earthquake prone countries. Follow local authority requirements and recommendations.

Restricted Access

- Radio equipment must be installed in restricted access areas.
- The indoor unit and associated power supply should be installed in lockable equipment rooms, closets, cabinets or the like.
- Access to the tower and ODU/antenna location must be restricted.

Chapter 2. Planning

This chapter provides planning guidelines for the installation of radio links. The guidelines apply to existing or newly completed sites.

Network, route and link planning is not addressed. These are topics best covered by publications such as the *Microwave Transmission Design Guide* by Trevor Manning, an Artech House (Boston & London) book.

The following system planning topics are covered:

Path Engineering

This section introduces some of the key considerations, checks and guidelines for path engineering. (It does not detail the engineering process as this constitutes a volume in its own right).

At the outset, transmission capacity requirements and quality objectives must be understood and agreed. All radio systems experience some quality of service degradation so it is essential that the quality level needed is balanced against system design constraints of path route(s), site availability, the equipment chosen, its configuration, future requirements, and cost.

From a basic route plan for a link or a network of links, the detailed radio planning can commence, where each hop must be designed to meet the agreed quality objectives.

Radio link performance is affected by various propagation anomalies, such as rain fade, reflections, and ducting. However, a thorough understanding of microwave propagation and fading mechanisms can allow an engineer to design a path that is robust even under the most difficult conditions.

Path Planning Guidelines

Table 2-1 provides an overview of path planning checks and criteria.

Table 2-1. Path Planning Checks and Criteria

Topic	Checks and Criteria
Path Engineering	This is a key activity in laying out any network. It is an activity best performed by experts in the field.
Path Profile	Regardless of path length, a baseline path profile must be prepared using a map of suitable resolution or a credible digitized data base. This baseline profile is the starting point for all subsequent line of sight verification and path engineering.
Radio Path Parameters	Microwave relies on clear line of site (LOS). For short paths it is normally safe to visually inspect a path to verify LOS. For longer paths, the geographical terrain characteristics, refractivity gradients, and rainfall rates can have a major impact on path performance. • Reflective surfaces such as flat smooth terrain, over water shots, sides of near-field buildings, and diffractive terrain boundaries need careful consideration. The longer the path, the more important this is. • Where a path is prone to such effects, reflection and/or diffraction analysis is essential to help predict their effect and, if significant, how they can be mitigated without having to consider changing to an alternative path. • Visual path profiles are essential to check and measure obstacle heights along paths, and to characterize terrain types. Don't rely solely on map-based path profiles. • Refraction by the earths atmosphere causes a radio ray to bend slightly downward in a normal atmosphere, or up in abnormal conditions where the density of the air increases with height. Of particular interest is the change in value of refractivity over the microwave front; the gradient of refractivity. The gradient can change over height, and with time, to provide various anomalous propagation conditions for beam spreading, ducting and multipath. Refractive index data is available for all geographic regions, which can characterize the likelihood of fading for different times of the day and for seasons of the year. • Correct average temperature and rainfall rates must be entered into the path availability calculations, and where appropriate account for any local anomalies, such as areas where rainfall rates are much higher than generalized for the region. Rainfall primarily affects transmission at frequencies above 10 GHz; below 10 GHz its effect can generally be disregarded.

Topic	Checks and Criteria
Antenna Height	Never assume that the higher up a tower an antenna is installed, the better the chance that path performance will be optimized. Quite apart from unnecessary additional cost and tower wind loading, antenna height can be used in the path design to help screen out unwanted reflective surfaces by using foreground obstructions. The cost of leasing space on a tower is usually based on antenna diameter (wind and weight load) and antenna height on the tower.
Future Scope for Path Obstructions	Check the potential for the path to become obstructed either permanently or temporarily. The growth of trees or building construction activity may compromise the path. Or a path may become temporally obstructed by construction machinery (cranes), ships and aircraft.
Equipment Parameters	Ensure appropriate equipment design/performance criteria are used for the link: • A good design correctly considers the balance between installed cost and how important a link is in the network. • Ensure that correct radio, feeder, and antenna specifications are used. For single antenna protected operation, ensure appropriate splitter losses are used. • When a link is to be protected using hot-standby, space diversity or frequency diversity, ensure the rationale for selecting one over the other is soundly based. • Make appropriate allowances for field variances such as transmit power, receive sensitivity, cable attenuation, antenna gains, and similar.
License Considerations	All point-to-point microwave links, except those in the ISM bands, are subject to licensing by local authorities. This is to ensure most efficient use of the available resource (frequency bands and bandwidth), and that users are allocated a radio channel, which is for their exclusive use in its near geographical area. Preparing a license application can be done by a user, but unless experienced in microwave planning, it is best left to the experts.
Frequency Planning	This is a key activity in designing a network. It ensures that the choice of frequencies will not interfere with other links, or be interfered with by other links in the same geographical area. In some countries there is a database of available frequencies by band from which to make a selection for inclusion on a license application. In others, the link frequencies will be determined by the licensing authority. Where there are doubts about the integrity of the database or where interference is suspected, a frequency sweep may be needed to confirm the availability of a preferred channel.

Critical Design Steps

Critical design steps include:

- Define the design objectives for the engineering of the path.
- Establish baseline LOS by preparing a theoretical path profile using a map of suitable resolution or a credible data base.
- Complete the path and link performance engineering.
- Perform the frequency planning and interference analysis.
- Complete all licensing requirements stipulated by local law.

Site Survey

Performed ahead of the installation, a site survey ensures that a site is ready.

The completed survey should include the following:

- A pass/fail check list with comments as appropriate
- A site layout plan showing planned requirements or changes

Refer to Appendix A for an example Site Survey checklists.

Pre-Installation Planning

This section describes recommended planning processes before going to site to carry out an installation.

Good preparation ensures that all required pre-installation tasks are completed and all essential installation items are to hand so that an installation can proceed smoothly.

Scheduling

Prepare an installation and commissioning work plan. Use a timeline planning tool or a customized Excel spreadsheet to list all relevant action items against resources and time.

While useful for a single link, such planning is essential for networked multiple links. Use of structured planning tools helps ensure all processes are efficiently addressed.

Permits and Licenses

Ensure you have the required permits for the site, and licenses for the frequencies and equipment, including:

Possible Requirement	Comment
Site access	Permits may be required for personnel and vehicles to enter military or key national sites. Site owners and operators may require personnel to have security passes.
Local authority permits	May be needed before an installation can commence, particularly if the site is covered by visual or radio-wave protection ordinances or if there are public safety issues, for example, when installing an antenna on the side of a building.
Frequency, bandwidth, and transmit power	Licensed band operation normally requires a license-to-operate from the regulatory authority for the selected channel / frequency-pair.
Equipment	New-generation radios have capacity and other variables set in software requiring a license from the manufacturer. Licenses are delivered as an encrypted software file or as a software key on a plug-in card. Ensure any required software license is correct for the capacity to be installed.

Directions and Keys

Ensure that keys and security alarm codes for the site are available and that the installation crew get clear directions to the site. Include any special instructions, such as to watch for stock and to close all farm gates behind them, or to contact the operations center on arrival and on departure.

Installation Datapack

An important requirement is the installation and commissioning datapack. It must have all information needed by the installation crew for the links and sites involved, including:

- Network management interconnection and terminal IP address data
- Commissioning checklist
- As-built, final site inspection, and sign-off forms

Refer to Appendix B for example Installation and Commissioning formsets.

Equipment Verification

Before going to a site, check that the equipment to be installed is correct and complete. Unpack the equipment and inspect the contents to ensure that the packing lists and the box labels are what was ordered. Also inspect the accessories, especially any optional accessories ordered and other small items that may have been missed during packing.

Ensure the Tx/Rx terminal (Tx high or Tx low), and its associated antenna(s) and cabling goes to the correct site.

Bench Test

Carrying out a bench test to confirm correct link operation before despatch to sites has merit where sites are remote or distant, or installation deadlines cannot accommodate out-of-box failures.

Tools, Consumables, and Test Equipment

Ensure you have the required and expected tools, consumables, and test equipment before going to site.

Item	Description
Tools	Include the following: • A full range of tools for an electrical / telecommunications installation, including a multi meter, hot-air gun, and standard crimp tools. • Specialized tools as may be required for antenna and feeder installation, such as cut-off, flaring, crimp and bending tools for waveguide and solid-outer conductor coaxial cables. • PC-based craft tool, with the correct software version(s) and drivers, to configure terminal and link parameters, and to carry out performance and as-built testing. Ensure that the cables to connect to a terminal are included.
Consumables	Includes materials such as crimp lugs, dc and ground wire, silicon grease, weather-protective/conductive grease, zinc-rich paint, heat-shrink tubing, and an assortment of nuts, bolts, and washers.
Test equipment	Equipment as specified in the user manual for commissioning check procedures. Equipment required can include: • BER tester (E1/DS1, E3/DS3, STM1/OC3). Check whether an optical and/or electrical interface is required for an STM1/OC3 tester. • Ethernet circuit analyzer (for Ethernet traffic testing). • Waveguide, antenna, and coaxial cable sweep analyzer. • Ground resistance meter to measure the effectiveness of site and tower grounds.

NMS Planning

This section describes the NMS planning issues for an Ethernet-connected manager, with a focus on HSX' ProVision element management system (EMS).

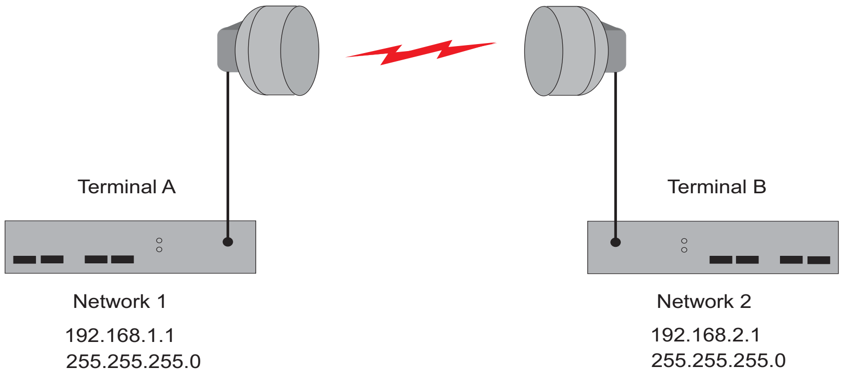
It is intended as guidance for someone experienced in IP addressing, such as a network or IT manager.

For networks (especially large networks) of HSX devices, the following guidelines must be followed to avoid planning difficulties. Issues that might not seem significant for a small network, can become major issues in a large or expanding network.

By planning the management network in conjunction with planning for the physical rollout of the network, the need to revisit sites to set IP addressing and perhaps install routers may be avoided.

IP Considerations

- Each radio is treated as a separate IP Network with the radios acting as a router.
- The radios decide if they should send NMS traffic across the microwave link based on routing. Therefore each radio has its own network ID and is assigned an IP address. For example:



  IP addressing for HSX radio devices typically requires as many IP host addresses as network IDs.

- If a large number of radios are deployed it may be necessary to use Variable Length Subnet Masking (VLSM) to make efficient use of IP addresses.

Address Ranges

Where management networks are network-address prolific a Class C address range should be a first choice, but with subnetting Class A and Class B addresses can also provide a large number of network addresses. Essentially, any non-Internet range of addresses can be used. Or an Internet address range can be used providing there is no gateway to the Internet. Example address ranges include:

Class A: 10.x.x.x with a mask of 255.255.255.0

Class B: 172.1.x.x to 172.10 with a mask of 255.255.255.0

Class C: 192.169.1.x to 192.255.255.x with a mask of 255.255.255.0

The non-Internet class B address space 172.16.x.x is not appropriate for radio networks except at the connection point to NOC LAN segments.

For some radios the manufacturer will advise that a specific range of addresses must not be used for the reason they are required for internal (embedded) addressing within the radio. An example of this is HSX's Eclipse, where the address range of 192.168.255.0 to 192.168.255.255 must not be used.

Routing Protocol

Generally static routing is the default routing option. For some radios it is the only option. It requires manual configuration of the routing table and any subsequent reconfiguration.

Dynamic routing makes use of a protocol such as OSPF or RIP. These update the routing table held within each router through a mutual exchange of messages. In most instances it should only be necessary to enter the IP address for the terminal and then select OSPF or RIP, depending on the capabilities of the router. Compared to static routing, dynamic routing requires much less configuration management by a network administrator.

HSX's Altium radio uses RIP version 1 (RIP1) routing protocol. The Eclipse radio offers OSPF, RIP1, or RIP2.

RIP has a 15 IP-hop limitation, which means contiguous chains of radios cannot exceed 15 IP hops[1] without the use of routers to mediate. This hop limitation is a management issue only, it does not affect traffic. OSPF does not have this IP hop limitation.

Some radios such as the HSX's XP4 and DART do not use routing tables. Instead they employ a simple IP forwarding or routing mechanism, meaning complex topologies where branching exists may require the use of a router at certain junctions if the broadcast mode is not used.

Summary IP Address Assignment Requirements

For detailed information on the establishment of management connectivity and addressing, refer to the User Manual for the radio type.

Device	IP Address Requirements
Eclipse Node, Eclipse Terminal non-protected, Altium, DART, DXR 700, DXR 100, Spectrum II *SNMP*, XP4 non-protected	Assign an IP address to each device
Non-protected XP4 or DART link *configured with a single NMI option board* (NMI board at one end of the link only)	Assign an IP address to the NMI equipped radio only
Protected Eclipse Terminal (protected IDUs) and protected XP4	Assign two unique IP addresses; one for each IDU in the protected pair.
Spectrum II, Quantum, M-Series, LC	These are legacy radios. All use TNet, which is a proprietary protocol that cannot be transported across an IP network without the use of an intermediary proxy agent running on a Windows NT-4 server. The proxy agent: • Identifies the managed HSX TNet radios and AIU • Assigns a subnet address to each TNet radio and AIU • Assigns a radio address to each TNet radio and AIU • Supports configuration of multiple physical TNet subnets

[1] For radio links, which are back-to-back connected by an Ethernet cable, each link represents two IP hops, meaning a maximum of seven hops before a routing intermediary is required. For radios such as HSX's Eclipse, its nodal concept means a maximum of 15 hops can be traversed before the RIP limitation applies.

Device	IP Address Requirements
XP4, DXR 700, and DXR 100	Do not support loop topologies without the use of routers to mediate. Please contact Harris Stratex Networks to discuss.
VoIP EOW (Voice over IP Engineering Order Wire)	The IP addressing requirements may call for each node to be addressed by every other node, which may differ from a management network where routing is biased towards sending data to the NOC.

Identify any requirements for third party equipment, such as routers, switches, and cabling.

- Where an NMS needs to transit a PDH circuit at E1/DS1 or sub E1/DS1, specialized muliplexers or routers can be used. Please seek advice from Harris Stratex Networks for such requirements.
- Disjointed management networks may be interconnected via routers/modems over leased lines.

If further information is required, contact Harris Stratex Networks.

Golden Site Installation

A Golden Site is a reference site; a site where the quality of the workmanship and the installation practices used are designed to set the standard for all other installations in a network.

Typically it is installed under the guidance of an experienced installer or trainer, and is particularly effective if completed in conjunction with a formal training course, where the trainees are doing the installation under the watchful eye of the trainer.

Usually a Golden Site is the first site of a new network rollout, but may also be a site where existing installation practices have been found wanting and a new site standard is required for remedial action.

Upon its completion a Golden Site can be used to assist on-going training of new installation personnel, both on-site, and in the classroom using photographic records of installation procedures.

A Golden Site may also prove invaluable in setting and agreeing required standards with installation contractors. Contractual requirements for standards and quality can be simplified if there is a Golden Site to formally refer to.

Chapter 3. Antenna Selection, Installation, and Alignment

This chapter describes the various types of point-to-point microwave antennas available for frequency bands 300 MHz to 38 GHz, their installation, initial alignment, wind loading, and environmental protection.

Antenna Types

Many antenna types are available to meet various electrical and mechanical specifications. Most commonly used are the parabolic antennas (grid, standard, focal plane, and shielded). Other types include flat plate (panel) and yagi.

Parabolic Antennas

There are two main types, solid (solid reflector) and grid (grid reflector). Grid antennas are available in frequency bands from 300 MHz to 3.5 GHz, at which point the reduced wind and weight loading benefits of the grid type lose out to solid antennas on electrical efficiency.

Solid antennas are broadly categorized into three distinct types: standard, focal plane and shielded.

Shielded types are often referred to as HP or high performance antennas by manufacturers.

Parabolic antennas are normally equipped with a mount to attach to a vertical 112-115 mm diameter pipe (vertical pipe mount).

Grid Antenna

Grid antennas are typically available for frequency bands from 300 MHz to 3.5 GHz with diameters from 1.2 m to 4 m. Polarization is determined by the orientation of the grids (and feed dipole). Grids horizontal for horizontal

polarization, vertical for vertical. The feeder mostly used is foam dieletric coax (eliminating pressurization requirements). Performance (gain, beamwidth, cross-polarization discrimination, front-to-back ratio, and VSWR) is comparable with an equivalent sized *standard* solid antenna.

Figure 3-1. Grid Antenna

To compare with other antenna types, refer to Table 3-1.

Standard Antenna

Standard solid antennas offer an economic solution where a high degree of back and side lobe radiation suppression is not necessary. A radome is not fitted, but is usually available as an optional extra. Single and dual polarization options are also usually available. Standard antennas are offered on frequency bands from 1 to 23 GHz.

Figure 3-2. Standard antenna

To compare with other antenna types, refer to Table 3-1.

Focal Plane Antenna

Focal plane solid antennas provide an improved front-to-back ratio specification compared to standard antennas. The reflector is deeper and the feed optimized to the reflector. A radome is usually not fitted, but is available as an optional extra. Single and dual polarization options are usually available.

Focal plane antennas are typically offered on frequency bands from 1.5 to 8 GHz.

In North America the focal plane is generally called a “deep dish” antenna, and is a minimum requirement at 5.9 to 6.4 GHz to meet FCC category A requirements.

Figure 3-3. Focal plane antenna

To compare with other antenna types, refer to Table 3-1.

Shielded Antenna

Shielded solid antennas include a shroud (shield) around the outer circumference, which has an RF absorbing material fitted on the inside. They offer high back and side lobe suppression and an optimized radiation pattern specification. They are usually offered in low profile, high performance, and ultra high performance versions, where ultra includes a more highly specified feed for optimum pattern performance. Single and dual polarization options are available. Shielded antennas are offered on all point-to-point frequency bands from 1.5 to 40+ GHz.

Figure 3-4. Shielded antenna

To compare with other antenna types, refer to Table 3-1.

A radome is a standard inclusion to reduce the wind load effect of the shield, and, for diameters up to 1.8 m, is usually solid plastic. For larger diameters, tensioned teflon fabric radomes are normally used.

Low profile versions, typically available for frequencies above 7 GHz, provide a reduced visibility antenna without seriously compromising radiation pattern performance.

The low profile shielded antenna is the type normally used with split-mount radio systems.

Other Antennas

Two other types of antenna encountered on the microwave radio bands are the Flat Plate and Yagi. Flat plate antennas are relatively new to the industry.

Flat Plate Antenna

Where low visual signature is a prerequisite, flat plate antennas with their compact, low profile dimensions provide a good solution. Their specifications fall into two categories:

- Medium gain with a relatively broad beamwidth on bands 2 to 13 GHz
- Higher performance with a specification comparable to compact shielded antennas on bands 23 to 38 GHz.

Figure 3-5. Flat plate 23 GHz high performance antenna

The lower specification antennas typically offer gains of between 13 and 18 dBi and with 3 dB beamwidths of 40° to 15° respectively. Front-to-back ratio and cross-polarization discrimination specifications are approximately half those of small diameter solid parabolic antennas. This type of plate antenna is most frequently deployed with 2.4 and 5.8 GHz unlicensed band radios.

The high specification plate antennas offer gain, beamwidth, cross-polarization and front-to-back ratio specifications comparable to a 0.3 m solid shielded (high performance) parabolic antenna. Currently these higher specification flat plate antennas are seen most widely on bands 23 GHz and higher, though examples are beginning to appear on the lower bands. Refer to Figure 3-6.

Figure 3-6. Flat plate 5 GHz high performance antenna

Yagi Antenna

Yagi antennas are offered for frequencies up to 2.5 GHz, where a typical high performance 12 element yagi can provide a gain of about 17 dBi with a 3 dB beamwidth of 20°. Figures for cross polarization discrimination and front-to-back ratios are often not stated.

For the 1.4 to 2.5 GHz bands the yagi is usually shrouded (installed inside a weatherproof protective tube).

Figure 3-7. 2.5 GHz shrouded yagi

For point-to-point microwave they have most application in lower capacity rural telephony and utility networks on bands 300 MHz to 1.4 GHz where their light weight, compact dimensions and low cost provide an attractive solution where antenna gains of not more than 12 to 17 dBi are required.

> For countries complying with ETSI standards there will be restrictions on their use, such as for the 1.4 GHz band (ETS 300 630) where a yagi may only be suitable for Class 1 applications (maximum 250 kHz channel width).

Selecting Antennas

There are many factors to consider when selecting an antenna. This section looks at a variety of factors, including electrical specification, how the environment may limit the choice, use of radomes, and shipping requirements.

Key electrical specifications include frequency, gain, beamwidth, cross polarization discrimination, front-to-back ratio and VSWR.

Key mechanical specifications include size, weight, wind loading, and the environment.

While it may appear that several different antenna types may satisfy a particular gain requirement, especially if the gain needed is low, in many countries the frequency management regulations will preclude the use of low-gain, wide beamwidth antennas on defined bands. The reason for this is that such antennas offer relatively poor directivity and interference suppression, and therefore restrict the efficient reuse of frequencies.

For microwave radio applications on bands 7 GHz and higher, the solid shielded (shrouded) antenna is almost universally used.

For information on typical radiation patterns and Radiation Performance Envelopes (RPE) for parabolic antennas, refer to Alignment Basics on page 3-25.

Parabolic Antenna Comparisons

Table 3-1 lists the advantages and disadvantages of the different parabolic antennas.

Table 3-1. Antenna Comparison Table

Type	Advantages	Disadvantages
Grid Antenna	• Light weight and low wind loading • Can be supplied in kitset form for easy and low cost transport to site • Low cost	• Not suited to sites where ice and snow loading is prevalent • Should not be used where high back and/or high side lobe suppression are required. Use solid focal plane or shielded antennas instead. • Supports only one polarization, vertical or horizontal

Type	Advantages	Disadvantages
Standard Antenna	• Low cost	• Should not be used where high back and/or high side lobe suppression are required. Use solid focal plane or shielded antennas instead.
Focal Plane Antenna	• Moderate cost • High back radiation suppression • Improved pattern shape compared to standard antennas	• Should not be used where high side lobe suppression is required. Use solid shielded antennas instead.
Shielded Antenna	• High back and side radiation suppression • Optimum pattern shape • Radome is included	• Higher cost • Higher shipping costs compared to other parabolic antennas as a result of its additional bulk

Radomes

Basic standard and focal plane parabolic antennas are not normally provided with a radome, but a molded plastic radome should be available as an option. For shielded antennas a radome is always included. Radomes are not applicable to grid antennas.

A radome fitted to a basic antenna will significantly reduce wind loading and provide additional protection for the feed and the face of the antenna against the accumulation of snow, ice and dirt. Radomes are normally available in standard and extra strength versions, the extra strength being applicable at sites where wind speeds in excess of 200 kph (125 mph) may be experienced.

For basic antennas, the published performance figures *will not* include the slight degradation in gain and VSWR when a molded plastic radome is added. Check the manufactures figures for this data. The attenuation of a standard radome at 7/8 GHz will typically be between 0.6 and 1 dB, rising to 2.5 to 3 dB at 18 GHz. VSWR will increase by about 0.3. For shielded antennas where the radome is standard, the performance figures *will* include the impact of the radome.

Regulatory Compliance

For regulatory purposes antennas are primarily classified by their RPE (Radiation Pattern Envelope) and XPD (Cross-Polar Discrimination) parameters. The standards most referred to are issued by ETSI and FCC, specifically:

- ETSI EN 300631, for 1 to 3 GHz
- ETSI EN 300833, for 3 to 60 GHz
- ETSI Draft EN 303217. Subsets 4-1 and 4-2 specify system-dependent requirements for antennas, which for the most part are based on the antenna sections within EN 300 631 and EN 300 833.[1]
- FCC Part 101

The RPE directional characteristics (co-polar and cross-polar) impact network planning for path distances and interference management. The regulatory requirements focus on interference management as this determines the frequency reuse within a geographical area; the more demanding the RPE, the less the interference from an antenna of equal gain, and the greater the number of links that can be located within the same band in the same geographical area. The regulatory requirements, which are established in concert with industry recommendations, endeavour to provide an equitable trade-off between highly demanding RPEs and the cost/size/weight of the antennas.

ETSI standard Draft EN 302217-4-1 (October 2003), defines four classes of antenna according to maximum co-polar RPE limit masks. These in turn are sub-divided by given frequency ranges of operation. Class 4 is most demanding, Class 1 least. Figure 3-8 shows proposed RPE masks for Classes 2 to 4, for frequency bands 3 to 30 GHz. Class 1 antennas are not shown and are defined as those exceeding Class 2 limits (a separate annex in EN 302217-4-1 provides Class 1 limits).

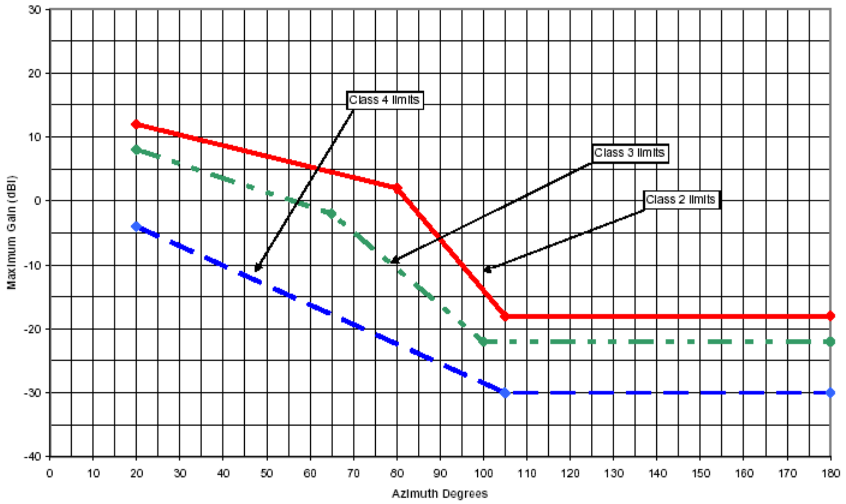
The RPE masks focus on off-axis side lobe performance, they do not define performance for angles close to the boresight direction (main beam). Guidance on typical main beam patterns for solid antennas is provided in Annex C of EN 302217-4-1.

The actual ETSI Class of antenna required for a particular frequency band within a territory will be determined by the licensing authority for the territory/country. Within the European community the RPEs proposed in EN 302 217-4-2 [6] for bands above 3 GHz, are only of classes 2 or higher, as Class 1 antennas are no longer considered suitable. The rationale is that the increasing demand of spectrum in European countries requires the use of more demanding antenna RPEs.

1 Once ratified, EN 3202217 will replace EN 300631 and 300833.

FCC Part 101.115 sets out the requirements for directional antennas based on maximum beamwidth, minimum gain, and minimum off-axis radiation suppression. For most frequency bands an A and B category antenna is specified. Standard A has the more demanding RPE and is to be used in all areas not classified as ‘low frequency congestion’. Standard B may be used for areas classified as low congestion.

Figure 3-8. Draft ETSI co-polar RPE masks for antenna classes in the range 3 to 30 GHz



When planning a network, ensure the antennas selected meet the relevant regulatory requirements. If in doubt, check with the antenna manufacturer.

Antenna Specifications

This section looks at the typical specifications for a given antenna, including

- Frequency on page 3-10
- Regulatory Compliance on page 3-8
- Gain on page 3-10
- Beamwidth on page 3-10
- Cross-polar Discrimination on page 3-11
- Front To Back Ratio on page 3-11
- VSWR on page 3-12

Frequency

The frequency of an antenna is expressed as an operating frequency band, such as 6.425 to 7.125 GHz, and is usually aligned with CCIR band recommendations. Within the band all advertised specifications should be met.

It is possible to operate slightly out of band, say up to 2 percent, and to find that overall performance is only slightly compromised. In most instances the only significant variation will be in the VSWR/return loss figures, which on the wider bands primarily determines the band edges for an antenna.

If out-of-band operation is being considered:

- Check with the manufacturer for guidance.
- Check that changes in antenna performance do not infringe any regulatory performance requirement for the band.

Gain

Antenna gain is a measure of directivity and efficiency, and for parabolic antennas is primarily a function of antenna size.

- Directivity is the ability of an antenna to focus energy in a particular direction.
- Efficiency is how much of the energy fed to an antenna is actually transmitted (that which is not transmitted is lost as heat). Conversely, it is how much of the incident received energy is converted to a receive signal at the antenna port. Solid antennas typically have efficiencies ranging from 50 to 70 percent.

The gain figure for an antenna is usually measured in dBi, as gain relative to an isotropic radiator, which is a theoretically perfect antenna that radiates equally in all directions. In practice, the gain of an antenna is checked by direct comparison with a known standard, or is computer integrated from measured radiation patterns.

Three gain figures are usually given for an antenna: at the bottom, top and mid-point of the specified frequency band.

Beamwidth

The beamwidth of an antenna is defined as the angle between the two half-power (-3 dB) points on either side of the main lobe of radiation (half power beamwidth). For solid parabolic antennas, beamwidths typically range from a maximum of 15° on the lower frequency bands, to less than 1° on the higher bands. Like antenna gain, beamwidth is primarily a function of antenna size for a given frequency band.

Cross-polar Discrimination

Cross-polar discrimination (XPD) specifies in dB the difference between the peak of the co-polar main beam and the maximum level of a cross-polarized signal over an angle twice the 3 dB beamwidth of the co-polar main beam.

This cross-polar discrimination feature allows frequency reuse within a geographical area, permitting operation of closely located radios on the same or adjacent channels, through judicious selection of vertical or horizontally polarized antennas. The associated frequency planning process (interference planning) would also include the transmitter power, modulation, C/I ratio of the receiver, and antenna RPE.

Antenna cross-polar discrimination can also allow some radios to operate on the same frequency channel over the same path, with one radio using one polarization (V or H), and the other radio the other polarization[2]. Such radios usually require special equalization capabilities, such as XPIC (cross-polar interference cancellation).

Determining Polarization

Radio waves have two interacting fields, one electric and one magnetic. These two fields are perpendicular to each other, with the sum of the fields termed the electromagnetic field. The position and direction of the electric field with reference to the earth’s surface determines its polarization. For vertical polarization the electric field is perpendicular to the ground, for horizontal polarization the electric field is parallel to the ground. Depending on the antenna and its feed construction, the required antenna polarization is achieved by rotating the antenna or its feed.

Circular Polarization

Circular polarization is another form of antenna polarization, where the electromagnetic field rotates - as the wave front travels it spins. Depending on the antenna, the polarization (spin direction) can be clockwise or counter-clockwise. These antennas are not used on the licensed point-to-point digital microwave frequency bands.

Front To Back Ratio

The front-to-back ratio is a measure in dB of the of the highest rearward level of radiation from an antenna compared to the main beam. The rearward signal level is measured over an angle of 180° ± 40° relative to the main beam. At 7 GHz, typical ratios extend from 45 dB for a standard solid antenna to 70 dB for a high performance shielded antenna.

[2] Such operation is referred to as co-channel dual polarization (CCDP).

VSWR

The VSWR (Voltage Standing Wave Ratio) is a measure of impedance mismatch between the transmission line and its load. Applied to an antenna, the VSWR is measure of the mismatch between the antenna feeder and the antenna.

- For a perfect impedance match the VSWR figure is unity. When not matched the VSWR will be above unity, and the higher the mismatch, the greater the VSWR. (The nominal feed-point impedance for point-to-point solid and grid antennas is 50 ohms)
- When the VSWR is unity, all power to an antenna (apart from any resistance/ heating losses) will be radiated.
- When not at unity, a proportion of the power to an antenna will be reflected back to its source, with the amount reflected dependant on how bad the mismatch is.[3]
- The combination of the original signal traveling down a feeder (towards the antenna on transmit, or opposite during receive) and the reflected signal, sets up a standing wave on the feeder. The voltage ratio of the two signals, or waves, is known as the VSWR.
- An antenna will typically have close to unity VSWR at its mid-band (resonant) point, with the edges of its specified bandwidth representing the maximum VSWR points.
- Most antennas for point-to-point licensed band operation have a VSWR of less than 1.2:1. High performance antennas typically have a VSWR specification of less than 1.08:1.

VSWR Example

To determine how significant a VSWR figure is, consider the following for a typical 50 ohm antenna used in a licensed band point-to-point microwave link with a maximum transmitter power of 1 W. Table 3-2 gives the power losses for VSWR ratios of 1.1: 1 and 1.3: 1.

Table 3-2. Example Showing the Low Significance of VSWR

VSWR Ratio	1.1: 1	1.3:1
Viewed as	Good	Mediocre
Power loss due to antenna reflection at one end	0.01 dB	0.07 dB

3 Where the mismatch extends to a short-circuit or an open-circuit, the VSWR is infinite; all the forward power is reflected.

VSWR Ratio	1.1: 1	1.3:1
Power loss due to antenna reflection at both ends	0.02 dB	0.14 dB
Local forward power reflected	0.23%	1.7%
Local forward power transmitted	99.77%	98.3%
Reflected power returned towards transmitter	0.0023 W	0.017 W

The calculations in Table 3-2 show that:

- The power losses (in dB) are insignificant when fade margins of 15 to 35 dB are the norm. Even for a 1.5:1 VSWR, which gives a power loss of 0.18 dB, the power loss remains insignificant.
- The reflected power returned towards the transmitter (in Watts) of 0.017 for the 1.3:1 VSWR is low, and should not impact the performance of the transmitter.

Return Loss

Return loss is directly related to VSWR. It is a logarithmic ratio, measured in dB, that compares the power reflected by the antenna (back down the feeder), to the power that is fed into the antenna from the feeder.

Similarly it can be used to compare the receive signal power reflected by the receiver input (reflected back towards the antenna), to the power fed into the receiver front-end from the feeder.

For example, if an antenna has a return loss of 20 dB, which equates to a VSWR of 1.22:1, the reflected power is 20 dB *lower* than the forward power. Or put another way one percent of the forward power is reflected.

For a perfect match (no power reflected) the return loss would be infinite. For an open or short circuit termination, the return loss would be zero. The higher the return loss, the better.

The following equation describes the relationship between VSWR and return loss:

RL (dB) = 20 log10 {VSWR + 1/VSWR – 1}

For more information about the relationships between VSWR, Return Loss, and Power, refer to Appendix C.

Tower Loading and Environmental Considerations

In selecting an antenna for a particular site and support structure, wind and weight loading, ice loading, ice fall, and corrosion must be considered.

Wind, Ice, and Weight Loading

Wind loading results from wind forces acting on the antenna and its support structure. It does not take much flexing of a highly directive antenna, its mount or the tower to cause significant variation to the received signal level.

Ice loading is usually considered in tandem with wind loading for an antenna where the wind-speed rating for an antenna includes a layer of radial ice or compacted snow to a depth of 25 mm to 30 mm (1” to 1.18”). Ice loading is also directly applicable to tower ratings (or other support structure) for its ability to carry the extra weight and bear the additional wind load.

Weight loading of an antenna is a parameter used in conjunction with the wind forces acting on it to gauge the suitability of a tower or other support structure to carry the antenna.

Wind loading is separately considered for the antenna and its support structure:

The Antenna

Solid parabolic antennas are typically designed to *survive* wind speeds up to 200 kph (125 mph), and higher, with a radial ice loading of 25 mm (1 inch). Their *operational* wind speed rating is lower, with limits set by beam deflection parameters.

Some manufacturers offer heavy duty versions with stronger back structures, which provide survival ratings up to 320 kph (200 mph).

Grid parabolic antennas are typically rated for a survival wind speed of 200 kph (125 mph) *but* without ice loading. As for solid parabolic antennas, some manufacturers offer heavy-duty, high wind survival versions.

CAUTION

Grid antennas should not be used at snow and ice prone sites. They are not designed, nor are they specified, for an ice-loaded wind survival rating.

Where side braces or struts are supplied as standard they must be installed in accordance with the manufacturer’s instructions for the antenna to comply with its flex and survival specifications.

CAUTION

Parabolic antennas with a diameter of 1.8 m and larger normally require a side strut. However antennas designed for direct-mount ODUs, whose mount must support a coupler/combiner and two ODUs for single-antenna protected configurations, typically require a side strut on diameters 1.2 m and larger. If in doubt, check with the supplier.

Antenna Wind Loading, Operational

The operational wind-speed rating of an antenna is typically that for which temporary deflection of the main beam is within one-third of the half-power beam width of the antenna. (A one-third deflection typically results in a signal drop of about 1 dB).

This is the deflection measured in relation to the antenna mount; it does not take into account any deflection of the mounting structure.

Another standard in use considers the operational wind speed as that for which the main beam is not deviated by more than 0.1 degree with up to a 25 mm (1") ice loading.

Whatever the method used by a manufacturer, it is important to also take the deflection of the mounting structure into consideration during calculation of beam deflection.

The lower wind loading of smaller diameter antennas means they usually have a a higher operational wind load specification compared to larger diameter antennas from the same manufacturer.

In some instances a manufacturer can offer a higher operational wind-load performance through use of additional support struts.

For HSX direct-mount antennas the operational rating for the antenna and mount includes the loading of a coupler and two ODUs for a single antenna protected installation. Two specifications are provided, depending on antenna size:

- For 0.3 m to 0.6 m (1 ft and 2 ft) antennas, the maximum operational wind speed rating with 30 mm (1.18”) ice loading is typically 230 kph (145 mph).
- For a 1.2 m to 1.8 m (4 ft to 6 ft) antennas, the maximum operational wind speed rating with 30 mm (1.18”) ice loading is typically 190 kph (120 mph).

Antenna Wind Loading, Survival

The survival wind-speed rating of an antenna is the wind speed that the antenna can withstand without permanent damage or deformation. (Antenna will return to its original setting, with respect to the mounting structure, once the wind subsides).

Survival wind loading specifications with 25 mm (1”) radial ice loading range from 200 kph (125 mph) to 250 kph (155 mph), depending on manufacturer and antenna diameter.

For HSX direct-mount antennas the survival rating for the antenna and mount includes the loading of a coupler and two ODUs for a single antenna protected installation. Two specifications are provided, depending on antenna size:

- For 0.3 m to 0.6 m antennas the maximum survival wind speed rating with 30 mm (1.18”) ice loading is typically 250 kph (155 mph).

- For 1.2 m to 1.8 m antennas the maximum survival wind speed rating with 30 mm (1.18”) ice loading is typically 200 kph (125 mph).

Where struts are included with antennas they must be correctly installed. For more information on antenna installation and strut location refer to Attaching on page 3-23.

The Support Structure

Wind force data is supplied by all antenna manufacturers for the purpose of determining the axial, side, and twisting forces. It is used to calculate whether the tower (or other support structure) has the design strength and rigidity necessary to carry the antenna, the outcome of which may result in a not-to-exceed height maximum based on tower loading limitations. This loading limitation might be alleviated by:

- Using a lower-wind-loading antenna, such as a grid antenna for frequency bands up to 3.5 GHz.
- Incorporating a radome on a standard or focal plane antenna. Axial forces (front/back) on standard and focal plane antennas can be significantly reduced (halved) by incorporating a radome.
- Replacing selection of a standard shielded antenna with a lower profile version or changing to a standard antenna with radome.

The support structure includes the pipe mount. Ensure the pipe mount or other structure used to directly support an antenna is rigidly fixed to the main support structure.

Ice Fall Protection

At snow and ice prone sites adequate ice-fall protection must be provided for the antenna and its feeder cable and for the ODU (in split-mount installations). In the thawing process large chunks of falling ice or compacted snow from further up a tower can cause damage capable of knocking a link off the air. Check with the tower owner/operator if there is potential for such damage, and install a protective shield/grid if recommended.

Corrosion Protection

A corrosive environment may also influence the choice of antenna or its options.

At coastal or off-shore sites where wind-swept salt spray is prevalent, or at sites where chemical processes or the burning of fossil fuels is likely to affect the long-term structural integrity of an antenna, special anti-corrosive coatings or finishes should be considered. These usually take the form of special epoxy coatings and other corrosion inhibiting compounds and protective sealants.

Special attention should also be given to the protection of other exposed items of the installation, such as the ODU for a split-mount radio, the feeder cables, connectors, grounding points and any exposed lightning surge suppressors.

Input Connector

Coaxial connectors are used for licensed and unlicensed band operation up to about 3.5 GHz, whereupon waveguide connectors become standard for licensed band use. The waveguide connector will be a flange type, or a customized direct-fit for split-mount installations using a direct-mounting ODU.

Coaxial connectors do however remain an option on antennas for bands up to 8 GHz. An example is the unlicensed 5.15 to 5.85 GHz band, where Type N connectors are almost universally used.

Typical coaxial connector options are:

- 7/8” EIA
- F Flange Female
- 7/16” DIN Female
- Type N Female

Typical EIA and IEC waveguide flange options are:

- PBR
- PDR
- WR75
- CPR
- UG

Before using a waveguide flange coupling always double-check to ensure that the mating flange and gasket selected for the waveguide is correct for the antenna flange. Refer to Waveguide Connectors on page 5-12 in Chapter 5.

For split-mount installations the ODU normally fastens to the rear of the antenna on a radio-specific (customized) attachment with integral feed coupling. The antennas are supplied ready-fitted with the customized attachment and are specific to a radio manufacturer and model. Advantages of this solution include quick and easy ODU installation and no feeder loss.

Shipping

While radio hardware is becoming more compact and lighter, the size of an antenna is constrained by the laws of physics. For 1 m (3 ft) antenna diameters and above, the air freight costs for the antenna may be considerably more than for the radio.

Where possible, plan ahead to allow for surface transportation of larger antennas. In some instances the savings may amount to the cost of the antenna.

Some grid antennas are available as full kitsets and some standard and shielded antennas are available in split or semi-kitset form, which can reduce volume and cost.

Antenna Mount Installation

This section describes the pipe-mount frames to which antennas are fastened. Example installations for tower, building, and rooftop are shown.

Mount Types

The industry-standard mount is a pipe mount. This pipe is vertically oriented and is usually attached to a tower with heavy galvanized angle iron brackets and U-bolts. For fixing to the sides of buildings or to rooftops, purpose-built brackets or support frames are used to support the pipe mount.

All parabolic antennas are designed to fasten to nominal 112 mm diameter galvanized pipe (4 inch inside diameter water pipe), of varying lengths. On small diameter antennas their mounts may offer both 112 mm and 50 mm (2-inch) pipe-mount options.

For flat plate and Yagi antennas, 50 mm pipe mounts are typically used.

For rooftop mounting the pipe is normally attached to purpose designed parapet rails or frames. Another option is a non-penetrating platform mount, which has application on rubberized or bitumen finished rooftops. The platform is essentially a raft, weighed down by concrete blocks or similar, to which the pipe mount is “tripod” anchored.

Figure 3-9. Typical tower pipe mount for a small diameter antenna

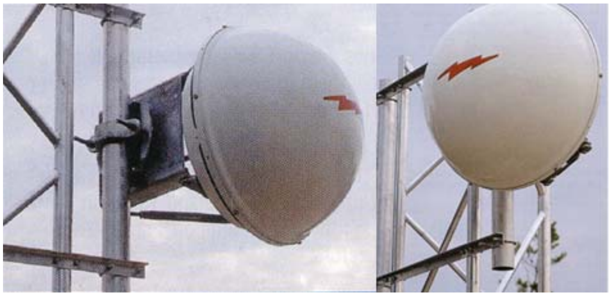


Figure 3-10. Typical tower pipe mount for a large antenna

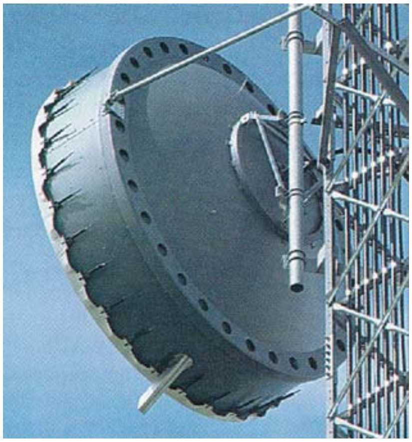


Figure 3-11. Example of a pipe mount fitted to the side of a building

Figure 3-12. Example of a non-penetrating rooftop mount

Figure 3-13. Close-up of a small non-penetrating roof mount

Positioning the Antenna Mount

Apart from the obvious need to position the mount at the right height, consideration must be given to its lateral location on a tower (antenna offset) for optimum ease of antenna installation, and for its attached ODU in a split-mount installation. Lateral location is also an important consideration for antennas requiring side bracing.

Where reflective surfaces on a link path are problematic, the height of the antenna may sometimes be used to advantage by using foreground obstacles as a screen.

If during commissioning unexpected path errors occur and a check indicates the problem may be due to reflections, look at relocating the antenna at a different height, or if a rooftop mount, look at moving it back from the parapet to remove antenna visibility to the reflective surface(s).

Positioning on a Tower

With three or four sided towers there is often a choice as to which leg or side of the tower to fasten the pipe mount to. Coupled with this is the option of mounting the antenna to the left or right side of the pipe (left or right offset). Antenna offsets (horizontal offset from the pipe mount axis) are usually more pronounced for split-mount installations due to the need to accommodate the piggy-backed ODU.

Left or Right Side Offset

Mount location for optimum left or right-side antenna offset may be decided with the following points in mind:

- Ease of antenna installation, and where antenna struts are required, correct siting for struts. A strut should be within a ± 25 degree angle from a right-angle to the antenna face. Refer to Figure 3-14 on page 3-23.
- Ease of access to antenna alignment adjusters. These typically provide a ± 20 to 25 degree adjustment for azimuth and elevation.
- For split-mount installations, ease of access to the ODU for maintenance.
- Visibility. The visual impact of an antenna may be minimized by choice of location.

Antenna Hoisting and Attachment

This section addresses the hoisting of an antenna and its attachment to a pipe mount.

Planning

Link planning will have determined the polarization of the antennas to be used and their initial pointing (using a compass reference or visual bearings).

For split-mount installations where the ODU fastens directly to the rear of the antenna, the antenna mounting bracket will carry the antenna offset from center to provide clearance for the ODU from the pole mount. For these installations the planning should state whether the antenna is left or right side offset. Refer to Left or Right Side Offset on page 3-21. An incorrect choice may make installation and removal of the ODU difficult and also mean less than best access to the azimuth and elevation adjusters.

When deciding the position, consideration of wind and ice loading, and ice fall, is required. Refer to Tower Loading and Environmental Considerations on page 3-14.

On the Ground

- Carry out as much assembly work as practical with the antenna on the ground.
- Set the polarization.
- For shielded antennas, ensure that the antenna drain-hole plugs have been removed from the bottom of the antenna shield and that they are installed in the top.
- Ensure that the elevation and azimuth adjusters are set for mid travel.
- Where practical an ODU should be attached to its antenna before being hoisted into position. Refer to Antenna Hoisting.

Antenna Hoisting

Small, compact antennas and ODUs can be hand carried up a tower. Larger antennas and some ODUs must be winched into place and supported there while being attached to their mount. This is a job for experienced and qualified riggers. Most countries require such personnel to be trained and certified in the practice of rigging and the use of hoisting equipment. This certification should be available for inspection when on the job. Similarly, hoist and winch equipment may need to be independently inspected and certified as being fit for purpose.

Correct procedures must be used to ensure equipment being installed, or existing equipment, is not damaged during hoisting and that other working antennas are not affected. In particular:

- Use manufacturer’s data to help determine the rigging needed for hoisting an antenna.
- For split-mount installations there is the option of attaching the ODU to the antenna before it is hoisted into position. This should only be attempted where there is no risk of the larger package causing hoisting, placement and fastening difficulties. If there is any doubt, install the antenna and ODU separately.
- When working around and with waveguide, ensure that it is not dented or deformed.
- Do not hoist equipment in front of existing (operational) antennas.
- Wind loading on an antenna can make hoisting difficult and dangerous, especially when winds are gusting. Install only when wind velocities are low and weather conditions are expected to remain stable.

Attaching

Double check that all fastening nuts and bolts are correctly torqued. Refer to Table 3-3 for correct torque settings. Note that there are two hardware types, stainless and galvanized; each requires different torque settings. Correct torquing is essential to ensure antenna survivability during high wind conditions.

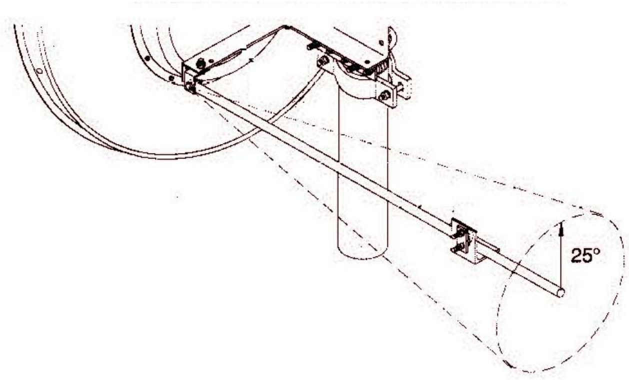
Table 3-3. Torque Table

	M5	M6	M8	M10	M12	M16	M20
Stainless Steel							
N-m	4.5	7.7	18.7	39.2	65.1	161	
lb.-ft	3.3	5.7	13.8	28.9	48	118.7	
Galvanized Steel							
N-m	2.7	4.5	11.1	22	38	95	185
lb.-ft	2.0	3.3	8.1	16.2	28	70.1	136

If side braces or struts are included, install according to the manufacturer's instructions. As a general rule, all antennas 1.8 m or greater must have a side strut installed, except for antennas with a customized mount for direct ODU attachment, which typically require a side strut on diameters 1.2 m or greater. If such antennas are received without a side strut, check with the supplier/ manufacturer to determine wind load specification compliance.

A strut must be installed to a tower member at an angle of no more than 25 degrees in relation to the antenna axis, refer to Figure 3-14 for guidance.

Figure 3-14. Antenna Strut Location



Antenna installation instructions should be included with all antennas. Follow these instructions to ensure correct installation.

Use a properly calibrated torque tool when checking for hardware tightness.

Install ice fall protection if there is potential for damage to the antenna and/or its feeder due to falling ice or compacted snow.

For antenna alignment details, refer to Antenna Alignment on page 3-24.

Antenna Alignment

Initial alignment should be carried out when an antenna is first attached to its pipe mount. Typically, visual or compass references are used to provide initial pointing data. For more information refer to Antenna Hoisting and Attachment on page 3-21.

Before You Begin

Prior to attempting alignment, ensure the following:

- That preliminary compass or visual alignment has been completed.
- Antennas at both ends (and ODUs for a split-mount installation) are correctly set for the same polarization.
- Frequencies and power level are set correctly (as specified in the link operating licence)
- Automatic transmit power control (ATPC) is disabled.
- Protection switching is disabled for protected and diversity links.

The following are required for antenna alignment:

- A rigger at each antenna
- A form of communication between the riggers, such as cell phones or walkie-talkies
- A means of measuring received signal strength

Alignment Basics

The purpose is to ensure that maximum signal strength is present at both ends of the link by having the signal from one antenna aimed directly at the center of the opposite antenna, and vice-versa.

CAUTION

During the alignment process there is a potential for interference to be caused to other operating links on the same or adjacent channels if the transmit antenna is pointing away from its designated path. Ensure the initial antenna pointing is set correctly before switch-on.

Alignment can be a tedious and time-consuming process, and may require repeated adjustment of azimuth and elevation until the desired receive signal level (RSL) is reached.

The signal from a typical parabolic antenna will have a main beam and a broad shoulder, which may or may not have well defined side lobes.

Remember that the half power beamwidths for parabolic antennas typically used with point-to-point microwave links range from 3.5° down to just 0.5°.

Shielded antennas, which are purpose designed to minimize side lobe transmission will normally have ill-defined side lobes, with adjacent peaks and troughs tightly spaced and within 10 dB in amplitude.

Figure 3-15 shows an indicative polar plot for a parabolic antenna (not to scale).

Figure 3-15. Indicative antenna pattern for a parabolic antenna

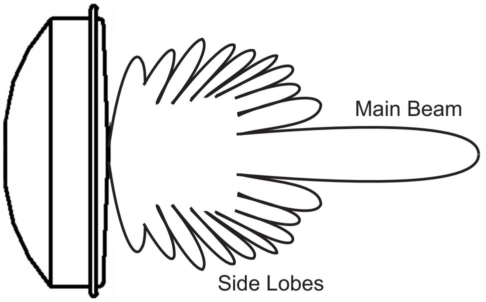


Figure 3-16 shows a typical radiation pattern envelope (RPE) and measured pattern for a parabolic antenna. Note the slight rise in level at 180°, which at approximately 80 dB down on the main beam indicates the antenna has an 80 dB front-to-back ratio.

Figure 3-16. Typical Pattern Envelope and Measured Pattern

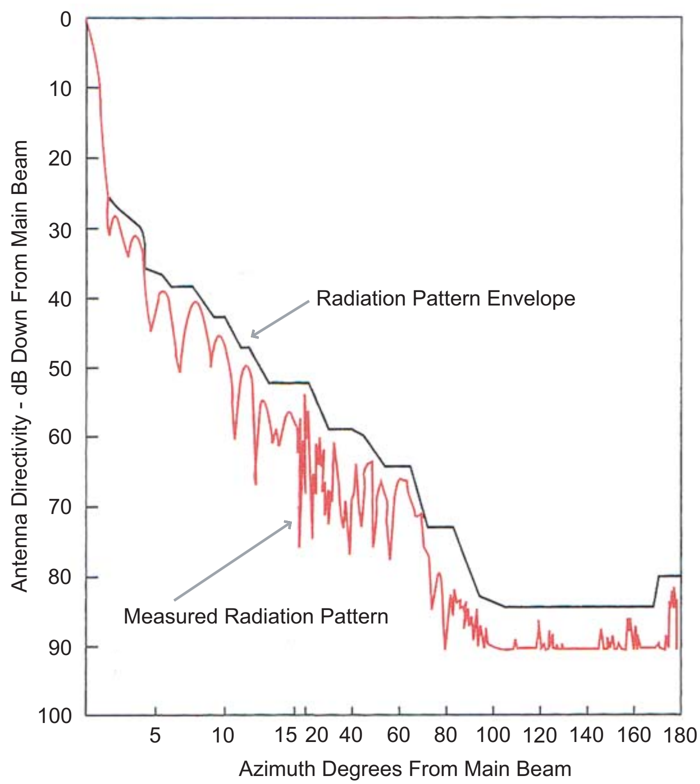
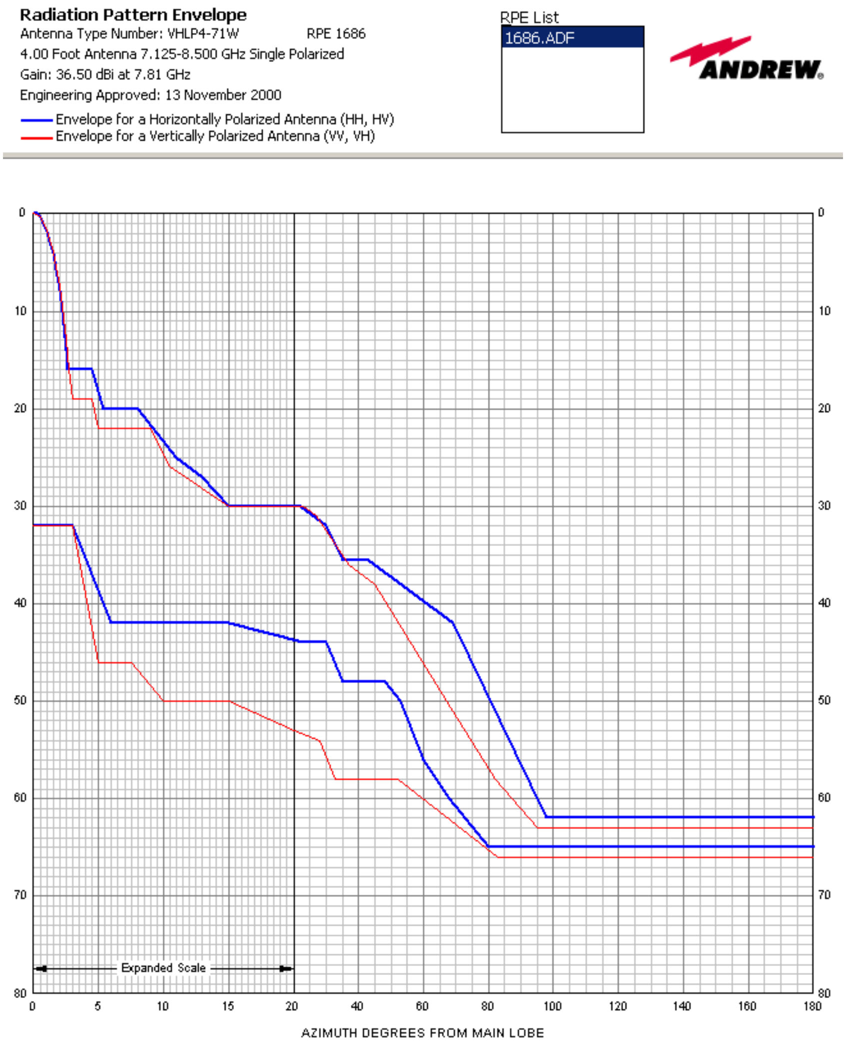


Figure 3-17 shows an example of a manufacturer's Radiation Pattern Envelope (RPE). Manufacturers normally guarantee their production antennas will not have any peak exceeding the RPE by more than 3 dB. The top pair of lines shows the E and H patterns for the wanted polarization; the lower pair show the corresponding E and H patterns for a cross-polarized signal. For the main beam the E and H patterns are normally coincident, but for the side lobes there can be up to a 5 dB difference.

Figure 3-17. Example Radiation Pattern Envelope (RPE)



Alignment Procedure

Antenna alignment involves adjusting the direction of each antenna until the received signal strength reaches its highest level at each end of the link. For an all-indoor radio, communication between the technician monitoring the receive signal level at the radio, and the rigger at the antenna will be needed. For split-mount radios the rigger should have direct access to a receive signal strength indicator (RSSI) at the ODU. This is typically provided via an RSSI

connector as a voltage for measurement by a multimeter.

Fine adjustment for azimuth (horizontal angle) and elevation (vertical angle) is built into each antenna mount. Adjustment procedures will be provided with each antenna.

If the horizontal adjuster does not provide sufficient range to locate the main beam, the antenna mounting brackets will need to be loosened and the antenna swivelled on its pole mount to locate the beam. Before doing so ensure the horizontal adjuster is reset for mid-travel.

Some mounts for larger antennas have a separately clamped swivel base to allow the loosened antenna to swivel on it without fear of slippage down the pole. Where such a mount is not provided a temporary swivel clamp can often be provided using a pair of pipe brackets bolted together immediately below the antenna mount.

Locating the Main Beam

Ensure the antennas are aligned on the main beam, and not a side lobe.

Once a measurable signal is observed, very small alignment adjustments are required to locate the main beam. For instance, a 1.2m antenna at 23 GHz typically has 0.9° of adjustment from center of main beam to the first null (0.4° to the -3 dB point). Antenna movement across the main beam will result in a rapid rise and fall of signal level. As a guide, 1 degree of beam width is equivalent to moving approximately 1.0 mm around a standard 114 mm (4.5 in.) diameter O/D pipe.

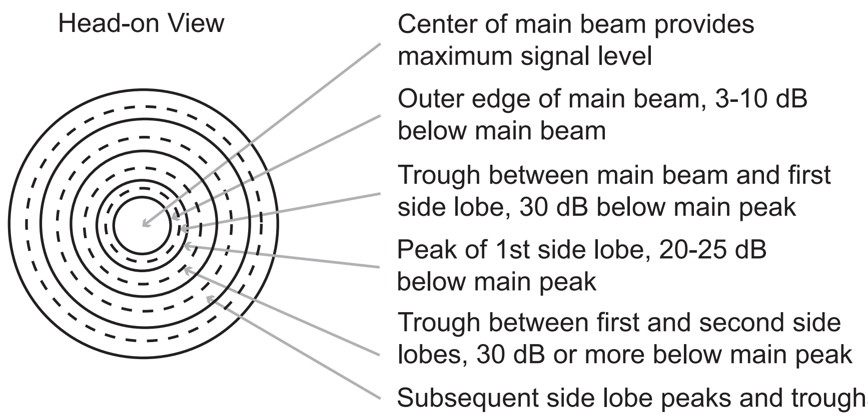
Antennas can be verified as being on main beam (as opposed to a side lobe) by comparing measured receive signal level with the calculated level.

Signal strength readings are usually measurable when at least a main beam at one end and first side lobes at the other are aligned.

The strongest signal occurs at the center of the main beam. The highest first lobe signal is typically 20–25 dB less than the main beam signal. When both antennas are aligned for maximum main beam signal strength, the receive signal level should be within 2 dB of the calculated level for the path. This calculated level should be included in the installation datapack for the link.

Figure 3-18 on page 3-29 is an example of a head-on, conceptual view of the beam signal strength, with concentric rings of side lobe peaks and troughs radiating outward from the main beam.

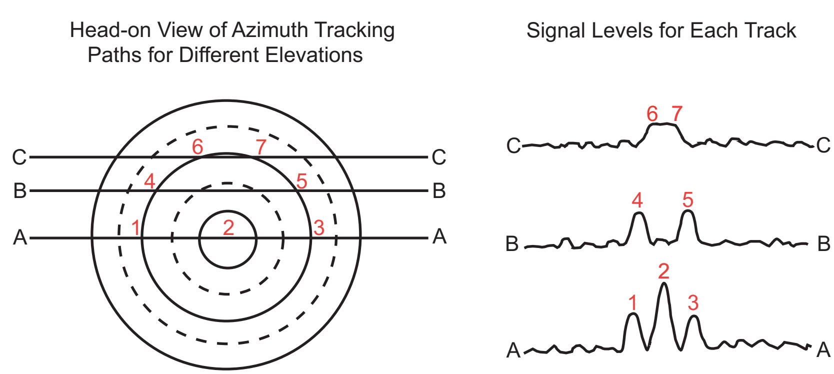
Figure 3-18. Indicative head-on signal pattern for a parabolic antenna



Tracking Path Errors

Side lobe signal readings can be confused with main beam readings. This is particularly true for the first side lobe as the signal level at its center is greater than the signal level at the edges of the main beam, and if tracking on an incorrect elevation (or azimuth) a false impression of main beam reception can be obtained. Figure 3-19 shows an example of this with a simplified head-on view of an antenna radiation pattern, and tracking paths for three elevation settings.

Figure 3-19. Example Tracking Path Signals



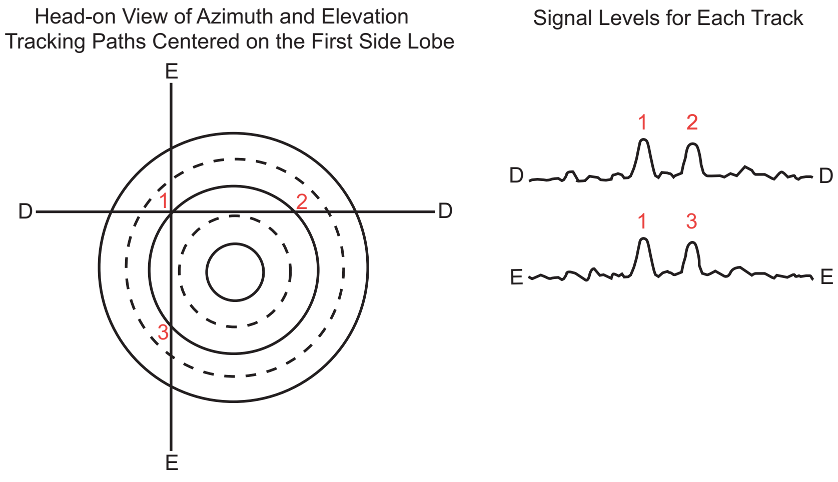
Line AA represents the azimuth tracking path of a properly aligned antenna. The main beam is at point 2, and the first side lobes at points 1 and 3.

Line BB represents the azimuth tracking path with the antenna tilted down slightly. Signal strength readings show only the first side lobe peaks, 4 and 5. In some instances the side lobe peaks are unequal due to antenna characteristics, which can lead to the larger peak being mistaken for the main beam. The correct method for locating the main beam in this case is to set the azimuth position midway between the first side lobe peaks, and then adjust the elevation for maximum signal.

Line CC represents an azimuth tracking path with the antenna tilted down further still. The first side lobe signal peaks (6 and 7) appear as one peak, leading to a mistaken interpretation of a main beam. The correct method for locating the main beam is to set the azimuth at mid peak, between 6 and 7, and then adjust elevation for maximum signal.

This first side lobe peaking is probably the most frequent cause of misalignment in both azimuth and elevation, especially so if one side lobe peaks higher than the other, as shown in Figure 3-20. A common error is to move the antenna left to right along line DD, or top to bottom along line EE, always ending up with the maximum signal at position 1.

Figure 3-20. Example Tracking Path Signals Centered on the First Side Lobe



Chapter 4. Split-Mount Radios - ODU and Cable Installation

This chapter addresses installation guidelines for the ODU, and IDU/ODU cable running, fixing, grounding, connectors and lightning surge suppressors. Refer to:

- Overview on page 4-1
- ODU Installation on page 4-2
- ODU Cable Installation on page 4-8

For guidelines on the installation of an IDU, refer to Chapter 7.

Overview

A Split-Mount radio has part of its electronics mounted outdoors with the antenna, and part indoors. The outdoor unit (ODU) is the RF transmitter/receiver; the indoor unit (IDU) contains the modulator/demodulator, multiplexer, control and traffic interface elements. The IDU and ODU are normally connected together using one standard-type coaxial cable.

By comparison, an all-indoor radio has all radio equipment installed inside and is connected to its antenna using a waveguide or coax feeder.

Most point-to-point radio installations for the licensed 6 to 38+ GHz frequency bands are split-mount, with the ODU direct-mounted to the rear of the antenna to provide an integral antenna feed. Exceptions include the US market where traditionally indoor radios are used for bands 6 to 11 GHz, and split-mount for 18 GHz and above. For the license-free 2.4 GHz and 5.8 GHz bands split-mount radios dominate.

By having the ODU mounted with the antenna, split-mount eliminates feeder losses, minimizes rack occupancy, and lowers installed costs compared to indoor radios.

ODU Installation

In split-mount installations the ODU attaches directly to the back of the antenna on a custom collar with an integrated antenna feed connection. The design and construction of the collar and coupling is specific to the radio model and manufacturer. This collar is normally supplied fitted to the antenna by the antenna manufacturer.

For correct ODU installation always follow the manufacturer's instructions.

Figure 4-1 shows an example of an antenna mounting bracket fitted with a customized ODU collar.

Figure 4-1. Antenna Mounting Bracket With ODU Collar

The antenna mounting bracket will carry the antenna offset from center to provide clearance for the ODU from the pole mount. The offset can be to the left or to the right. An installation datapack should include information on which side it is to be attached; left or right side offset. An incorrect choice may make installation/removal of the ODU difficult and also mean less than best access to the azimuth and elevation adjusters.

The ODU may be a single transceiver design (1+0 optimized), or dual transceiver (1+1 optimized). Dual transceiver ODUs may be fitted with a single transceiver for non-protected operation, or two for hot-standby or diversity operation.

Figure 4-2 shows two 1+0 ODUs fitted to a dual mount for protected operation.

Figure 4-2. Dual Mounted ODUs

For information on remote-mounted ODUs, protected installations, ODU grounding, and ODU temperature considerations refer to:

- Remote and Indoor Mounted ODUs on page 4-4
- Protected Configurations on page 4-5
- Outdoor Equipment Grounding - 6 Simple Rules on page 4-6
- ODU Temperature Considerations on page 4-8

CAUTION

Take care when bringing the ODU onto its antenna mounting bracket. Ensure no impact damage occurs to the ODU feed head and polarization rotator.

CAUTION

Do not install the ODU when it is raining. Moisture must not be allowed to get into the ODU/antenna feed assembly.

Antennas and ODUs are usually supplied from new with a self-adhesive seal over the feedhead flange to protect against the ingress of moisture and dust during transportation and handling. *Seals must be removed prior to installation*.

Remote and Indoor Mounted ODUs

Where direct mounting an ODU is not an option, the ODU can be remote mounted from its antenna using a short length of flexible waveguide, or coax at lower frequencies.

A remote-mounted antenna requires a normal industry-standard connector/ flange; not the customized collar/flange assembly for a direct-mount ODU. Figure 4-3 on page 4-5 shows an example of a remote mounted ODU.

Flexible waveguide used for this purpose should not exceed 2 m; preferably not more than 1 m. It is not necessary to install a dehydrator (desiccator) on such short runs.

Flexible waveguide or coax must be supported such that it cannot flex in the wind and that its routing does not put undue strain on the connectors. At lower frequencies the more robust nature of flexible waveguide means suitable support may be positioned every 30 mm to 60 mm (1 ft to 2 ft), but at frequencies 18 GHz and above the highly flexible nature of the waveguide means support may be required at 15 mm to 30 mm intervals (6” to 12”). Rod supports are recommended where direct fixing to steelwork is not possible; refer to Typical hanger and adaptor items on page 5-8.

Flexible waveguide must not flex in the wind. Ensure the ODU-to-antenna flex-waveguide or coax is properly supported.

For installations where the ODU is to be mounted indoors refer to Indoor Equipment Installation on page 7-1.

Many manufacturers provide a rack-mount kit for their ODUs, meaning a radio designed for split-mounting can be installed as an all-indoor radio.

ODUs do not normally have a gas-tight antenna connection, which means that for an all-indoor installation the standard practice of using a flexible jumper from the radio up to elliptical waveguide in the overhead cable tray should be followed, with a pressure window inserted at the jumper/waveguide junction and the dehydrator air-line connected to the waveguide connector. Refer to Chapter 5.

Figure 4-3. Remote mounted ODU

Protected Configurations

With single transceiver ODUs, two ODUs are needed for hot-standby or diversity operation. These can be connected to separate antennas but for hot-standby and frequency diversity configurations they are normally connected to a single antenna via a combiner, which impacts (attenuates) both the transmit and receive paths. For information on combiners refer to Combiners on page 4-5.

For dual transceiver ODUs it is more common to have a transmit switch and receive combiner, which when connected to a single antenna has a reduced impact on path attenuation. A typical loss figure for a transmit switch is 1.5 dB, which when used with an equal loss receive combiner of 3.5 / 3.5 dB, means the total one-way attenuation is 5 dB, compared to 7 dB for a comparable equal-loss combiner-only solution.

Combiners

Combiners may be either equal loss or unequal loss.

For equal loss combiners the loss (attenuation) per side is typically 3.5 dB (3.5 / 3.5 dB), which applies to both the transmit and receive directions, meaning the additional total one-way attenuation compared to a non-protected link is 7 dB.

Unequal or asymmetric combiners are frequently used on the rain affected bands of 13 GHz and above. These are combiners which have ratios such as 7 / 1.5 dB or 10 / 1 dB. The rationale for using unequal ratios is that they can be shown to lower annual outage due to rain fades as compared to links deployed with equal loss combiners.

Consider a 7.5 / 1.5 dB combiner with the 1.5 dB loss side assigned to the “A” or

main side. The “A” side additional path attenuation is just 3 dB, as compared to 7 dB for an equal loss combiner. Therefore, the “A” side has a 4 dB fade margin cushion (higher system gain) over an equal loss configuration. This can be significant during periods of exceptional rainfall, periods which fall outside the normally accepted rain outage model for the location, but which may occur several times a year. The downside is that if one “A” side fails the additional path attenuation *compared to an equal loss combiner* installation is 2 dB, or in an extremely unlikely worse case situation of both “A” sides failing, an additional attenuation of 8 dB. The conclusion is that the benefits of the extra system gain outweigh the downside of an “A” side failure, as the probability of a significant rain fade occurring while an “A” ODU (“A” Tx or Rx) is being repaired is not significant, given ODU failures occur less than once in 15+ years on average.

Outdoor Equipment Grounding - 6 Simple Rules

Correct grounding is essential for maximum lightning protection. Follow these six simple rules:

1. ODU ground wires must be a minimum of 16 mm^2 / 6 AWG.
2. ODU grounds must be connected to a tower ground bar or tower steel.
3. Any connection points to the tower ground bar or steel must be free of paint and oxidation to ensure a good low-resistance contact.
4. All outdoor ground connections must be coated with conductive (copper-based) grease to prevent corrosion and potentially high impedances to ground. Figure 4-4 shows and example of connection corrosion caused by a lack of conductive grease.
5. Never loop or spiral a ground lead, always keep as short as possible, angling in a downward direction. Figure 4-5 shows an example of how not to do it.
6. Never daisy-chain outdoor equipment grounds and do not stack multiple ground lugs on a single ground bar connection.
   - Each item must be individually grounded to the tower grounds or steel.
   - If connections are stacked and it becomes necessary to replace a ground wire, you will have to remove higher-stacked grounds to remove the wanted one, which will disrupt ground connectivity to other equipment.

Figure 4-4. *Incorrect* Outdoor Ground Connections

Figure 4-5. *Incorrect* Routing of Outdoor Ground Wires

CAUTION

Always follow any special manufacturer instructions for ODU and associated lightning surge suppressor grounding.

ODU Temperature Considerations

An ODU is normally specified for a maximum ambient temperature of 50° to 55°C (122° to 131° F). This is a shaded temperature limit (no solar gain). In equatorial climates where ambients may exceed 45° C (113° F), the additional solar gain may result in over-heating. Solar gain can add 10° C or more to the internal ODU temperature.

In hot equatorial climates a sun shield for the ODU should be considered. As well as ensuring ODU temperature limits are not exceeded *through solar gain*, a shield will help reduce internal temperatures. As heat stress is a primary cause of premature component failure, any reduction in operating temperatures will assist long term reliability of the ODU.

ODU Cable Installation

This section provides guidance on running and fastening the IDU/ODU cable, cable grounding, and the fitting of cable connectors.

Refer to:

- ODU Cable Running and Fastening on page 4-9
- ODU Cable Grounding on page 4-10
- Cable Connectors on page 4-12
- Weatherproofing Connectors on page 4-13

The ODU cable is typically a small diameter 7 to 10 mm (3/8 to 1/2 inch) braid or solid outer coaxial cable. The sheath is usually polyethene or polyethylene, the latter being preferable for its higher resistance to minor pin-hole deformities.

The manufacturer’s recommended cable usually provides for a maximum 250 m to 300 m cable run, the maximum being determined by the cable resistance and resultant voltage drop between the IDU and ODU. Larger diameter cable, which generally has lower resistance, may be used to provide extra IDU to ODU separation.

ODU Cable Running and Fastening

Table 4-1 provides guidelines for IDU/ODU cable running and fastening.

Table 4-1. IDU/ODU Cable Running and Fastening Guidelines

Planning the route	• Use cable supports or ties for securing the cable to the main structural frameworks. • Run adjacent to other *coaxial* cables except where their routing is poor. • Do not run the cable adjacent to the tower ground wire or electrical services cables. • Select a route that is unlikely to be damaged by riggers on the tower, or restrict their movement on the tower. • Do not run the cable along the topside of cross-members (to avoid it being stepped on). • Do not run the cable along the tower legs (as these are the primary attachment points for pipe mounts). • Ensure there is support for the cable at intervals of not more than 1 m (3 ft) (or the interval specified in the equipment installation manual). • Do not use a bending radius less than that specified by the cable supplier. • Ensure the cable cannot flex in the wind. Where necessary use rod supports, such as for the section of cable between the tower and the ODU. • Ensure there is adequate physical cable protection at locations where ice fall from towers may occur.
Supporting the cable	• Normal practice is to use UV resistant cable ties, though cable hangers and adaptors can be used. • Do not tie to an existing feeder or ODU cable. • Do not tie to a lightning ground wire or to electrical cables. • Do not overtighten the ties.
During installation	• Cut cable-tie ends off flush with the grip. Left exposed, cut ends can be sharp enough to cause a serious skin injury. • Where the cable is entering a building via a wall feed-through assembly, provide a drip loop or ensure the cable runs at a slight uphill angle *to the building* to avoid water entry to the building via the cable. • If a maintenance loop is required, it should not exceed 3 m (10 ft).

Identification	Provide weatherproof cable identification tags for each end of the cable. This is especially applicable to sites with multiple radio installations.

ODU Cable Grounding

The IDU/ODU cable must be correctly grounded and fitted with an appropriate lightning surge suppressor to prevent equipment damage due to lightning strikes on the antenna or its support structure.

For guidelines on lightning surge suppressor selection and installation refer to Chapter 4.

Unless otherwise specified by the equipment supplier, the IDU/ODU cable must be grounded at the following points:

- At the top of the cable run where the cable branches off the tower to the ODU.
- At the base of the tower where the cable branches off to the building.
- At the point of entry to the building.
- Where the cable run on a tower exceeds 30m (100ft), a cable ground should be fitted at not more than 30m intervals or a split thereof. For instance, if the vertical run is 45m, a cable ground should be installed at the mid-point.

Cable grounding kits will be supplied or be available from the equipment or cable supplier. Ensure the correct kit for the cable is used. This is especially important for braided-outer-conductor cables where an incorrect kit may provide an inferior connection to the braid or inferior protection against water entry.

Cable Grounding Guidelines

Cable grounding kits are supplied with fitting instructions. Other points to note are:

- Connect the ground wire to the tower or structure at a sharp downward angle. Lightning takes the shortest path to ground.
  - The ground wire must not be installed at an upward angle.
  - The ground wire must not be looped or spiralled.
  - If the ground wire is supplied with a crimped lug and the cable is too long for a correct installation, cut the lug off, trim the cable to length and attach a new crimp lug.

For guidance on fitting crimp lugs refer to Ground Terminals and Lugs on page 7-7.

- The tower/structure end of the cable is normally bolted to a clamp such as an angle adaptor. Before fastening the clamp, scrape any paint or oxidation from the tower points of contact to ensure there will be a good low-resistance contact. Afterwards, liberally apply zinc-rich paint or conductive grease around the clamp to provide protection against corrosion.
- At non-standard installations such as building tops or sides of buildings, follow the same general guidelines but where proper grounding points are not provided these must be installed first.
- Do not fit cable grounding kits during rain. To fit the kit a small section of outer sheath must first be removed to expose the outer conductor. During this process moisture must not be allowed to penetrate into the cable.

Cable Connectors

Connectors are supplied with instructions for fitting. If not supplied and there is uncertainty on correct cable preparation or connector assembly, check with the equipment or connector supplier. Correct installation is essential. Table 4-2 provides basic guidelines.

Table 4-2. Fitting Coaxial Connectors

Required considerations	Explanation
When removing the jacket- *all coaxial cable*	Take care when removing the jacket to keep the outer conductor intact. A scored outer conductor will weaken the cable and, for a solid outer cable, may cause the outer conductor to break or crack when subsequently bent.
When removing the jacket *-solid outer conductor cable*	Use the cut-off and strip tool specifically designed for the particular cable being used.
Crimped connectors	Always use the correct crimp tool for the connector. Use of a general purpose crimp tool may result in an unsound physical connection, which may deteriorate over time. Do not over crimp.
Fastening connectors	Fasten connectors (male to female) by hand only, unless otherwise specified. Type N connectors should only be hand tightened.
Weatherproofing	All outdoor connections must be made weatherproof. Refer to the topic Weatherproofing Connectors on page 4-13.

CAUTION

Ensure all moisture and dust is excluded from the connector assembly during attachment.

Weatherproofing Connectors

These instructions cover the weatherproofing of connectors.

All outside connections must be weatherproofed. Weatherproofing kits or tape should be supplied, or be available from the equipment or cable supplier.

Refer to:

- Mastic Tape Weatherproofing Kit on page 4-13
- Self Amalgamating Tape on page 4-14

Mastic Tape Weatherproofing Kit

A typical weatherproofing kit includes rolls of butyl mastic tape and vinyl tape.

A three-layer wrap process is recommended:

- An initial layer of vinyl tape is applied to facilitate easy strip-back when cable disconnection is required.
- The second layer uses butyl mastic tape. It is this tape that provides the weatherproofing.
- The final layer of vinyl tape ensures good amalgamation and adhesion of the butyl tape and provides UV protection.

CAUTION

Special attention must be given to ensuring the mastic tape seals cleanly to the primary surfaces, such as to the cable jacket, or to the barrel of a bulkhead-mounted female connector.

Wrapping Guidelines

1. Ensure connectors are firmly hand-tightened, dry, and free from all grease and dirt. If necessary, clean with a rag lightly moistened with an alcohol-based cleaner.
2. Pre-wrap using vinyl tape. Use a 25% overlay when wrapping. To avoid curl-back do not stretch the tape too tightly at the end point.
3. Apply the mastic tape using not less than a 33% overlay. Where possible the tape must extend 25 mm (1”) past the pre-wrap tape ends. Lightly firm over by hand to ensure a full seal at all points, using a tear-off section of the butyl tape backing to protect your hands. *Check that there is no possibility of water entry before proceeding to the next step.*

CAUTION

There must be a full seal beyond the initial vinyl wrap endpoints for weatherproofing integrity.

4. Cover the mastic tape with a final layer of vinyl tape. To avoid curl-back, do

not stretch the tape too tightly at the end point.

CAUTION

To avoid displacement of the mastic tape, do not stretch the final layer of vinyl tape across sharp corners and edges.

Self Amalgamating Tape

Self amalgamating tape is normally applied as a single-layer protective wrap, where it binds to the host and self-amalgamates to provide a continuous seal. It is especially useful in tight locations where mastic tape application would be difficult.

Wrapping Guidelines

1. Ensure connectors are firmly hand-tightened, dry, and free from all grease and dirt. If necessary clean with a rag lightly moistened with an alcohol-based cleaner.
2. Apply the tape tensioned, using at least a 75% overlay. The tensioning (slight stretching) of the tape is required to allow it to bind to the host and to amalgamate the layers.
3. Where possible, apply the tape 25 mm (1”) past the ends of the connector barrels to ensure the weatherproof bond extends beyond the areas requiring protection. Regardless, the application of the tape must be such that there is no doubt as to the effectiveness of the sealing provided.
4. To avoid curl-back, do not stretch the tape too tightly at the end point.
5. To assist UV protection, a post-wrap using vinyl tape may be applied.

Chapter 5. All Indoor Radios - Feeder Selection and Installation

This chapter provides guidelines on the selection and installation of waveguide or coaxial cable for all-indoor radios, including running, fixing, grounding, and connectors. For guidelines on installation of all-indoor radio equipment, refer to Chapter 7.

Overview

There are two types of feeder for all-indoor radios:

- Waveguide
- Coaxial Cables

Attenuation and cost considerations generally determine the choice. While coaxial cable allows solutions at frequencies up to 10 GHz and higher, the attenuation (dB/100m) is many times that available from a waveguide solution at these same high frequencies.

Other factors affecting choice include VSWR, power handling, feeder flexibility and the environment.

As a general guideline, feeder selection for point-to-point microwave can be grouped for bands above and below 3 GHz:

- For frequency bands below 3 GHz **foam dielectric coaxial cable** is recommended:
  - Air-dielectric coax offers only marginally better attenuation performance and does so with considerable extra cost, both for the cable and for the additional need for a dehydrator installation. At 2 Ghz, 7/8" foam dielectric coax has an attenuation of about 6.1 dB/100m, compared to 5.75 dB for air-dielectric coax.

    - Where attenuation on very long feeders is an issue, a lower attenuation figure can be achieved by waveguide, which offers a solution down to about 1.7 GHz. 7/8” foam dielectric coax has an attenuation of about 6.1 dB/100m at 2 GHz (4.8 dB/100m for 1 1/4 in.), whereas elliptical waveguide at the same frequency exhibits an attenuation of 1.2 dB/100m, but does so with much greater physical size, weight, minimum bend radius and cost. Cost must also include the need for a dehydrator installation. It may therefore be much more cost effective to use coax and go one size larger in antenna diameter to help offset the higher attenuation of coax.
    - Antennas with foam dielectric feedheads should be a first choice for use with foam dielectric feeders.
    - Where an antenna has an air-dielectric feedhead it is not necessary for the low Tx power installations being considered here to install a feedhead dehydrator (desiccator), when used with foam dielectric coax.
- For frequency bands above 3 GHz, standard grade **elliptical waveguide** is recommended. Exceptions include:
    - For very short runs, foam or air-dielectric coax may provide acceptably low signal attenuation and do so at much lower cost of supply and installation. Bear in mind that coaxial cables have a cut-off frequency (maximum frequency), which is diameter dependent; the larger the diameter, the lower the cut-off frequency. For instance, 1/2” foam coax can be used up to 9 GHz, 7/8” up to 5 GHz and 1 1/4” up to 3.3 GHz. But where there is a choice, such as at 3 GHz, the larger the diameter of the coax, the lower the attenuation. Check manufacturer’s data for details.
    - *Rectangular* waveguide has application as components within an elliptical waveguide system where space restrictions mean elliptical waveguide cannot be flexed sufficiently and still provide a sound engineering solution. Rectangular components include bends, elbows and twists.
- Where very low VSWR is a requirement, premium grades of coax, elliptical waveguide and matching connectors are offered by some manufacturers. (A very low VSWR should not be a requirement for the pt-to-pt digital microwave installations being considered in this guide. Refer to VSWR on page 3-12).
- The standard sheath/jacket material for solid-outer coax and for waveguide is polyethylene. As an option, a special fire retardant and non-halogenated sheath material is offered by some manufacturers. Its selection may obviate the need for conduit at some high-risk sites.

Waveguide and Coax Installation

This procedure describes the installation and testing of elliptical waveguide and the air-dielectric coax feeders. It also applies to foam dielectric coaxial feeders with the exception of the sections on pressurization.

For pressurization of waveguide and air-dielectric coax refer to Pressurization Equipment and Installation on page 5-21.

Where reference to waveguide is made in this section, it is to be interpreted as also including coaxial cable unless specifically stated.

Installation Precautions

If the feeder installation is on a tower or high building, correct safety procedures must be followed, and only certified riggers engaged to carry out the work.

Follow local site safety requirements. Regardless, where necessary set appropriate signs such as, “Danger Men Working Overhead” and “Hard Hat Area”, and the immediate danger area around the foot of a tower or building must be closed off to the public and vehicles.

System performance can be seriously degraded by the ingress of dust or moisture to waveguide, air-dielectric coax, or associated RF units and antenna flanges. Ensure that waveguide and cable ends and all flanges are covered/protected until immediately prior to termination and mating. This applies to all installation and equipment change-out situations.

Antennas with air-dielectric feedheads and waveguide components such as connectors, bends and twists are usually supplied from new with self-adhesive seals to protect against the ingress of moisture and dust during transportation and handling. *Seals must be removed prior to installation*.

System performance will also be degraded if the waveguide or coax is dented or crushed. Extreme care must be exercised during installation to avoid such damage. Similarly, consideration must be given to its placement on and about the the structure to minimize the potential for damage caused by personnel climbing the structure.

Tools

The following tools may be required:

- Cut-off tool or tin snips for waveguide
- Cut-off tool for coaxial cable
- Flaring tool for connector attachment
- Bending tool for waveguide (E & H plane)
- Dry-air hand or foot pump for pressurization
- Hoisting grip for pulling waveguide
- Jacks and spindle for waveguide drum
- Spanners for waveguide flange nut/bolt fixing[1]: M3 (5.5 mm, ~ A/F 7/32”), M4 (7.0 mm, ~ A/F 9/32”), M5 (8.0 mm, ~ A/F 5/16”)
- Adjustable spanners for large diameter coaxial connector back-shell fastening

Preparations

Prior to installation:

- Check the packing list for correct delivery.
  - Check that the *correct waveguide* type has been delivered and that it is of the *expected length*.
  - Check that the supplied connectors are correct for the job and that installation instructions and accessory kits are included.
- Unpack and check for damage.

  If the waveguide has been delivered on a drum, remove the battens and carefully remove or flatten any nails that could snag the waveguide during its payoff.
- Report any damage or shortages.
- Keep the drum vertical at all times and ensure the waveguide ends remain protected from moisture and dust ingress until connector termination.

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[1] Metric sizing of M3, M4 etc. refers to the metric diameter of the threaded section of bolt; M3 is 3 mm, M4 is 4 mm. The spanner size required is the distance across the flats of the bolt head, which for an M3 is 5.5mm, and for an M4 is 7 mm. The imperial A/F measurement (A/F = across flats) is in inches and while the A/F spanner sizes indicated are a close match they are not an exact conversion, and may therefore not fit precisely.

Waveguide Installation Guidelines

Prior to hoisting ensure all equipment to be used, such as ropes, pulley blocks and hoisting grips are fit for purpose and in a fully serviceable condition.

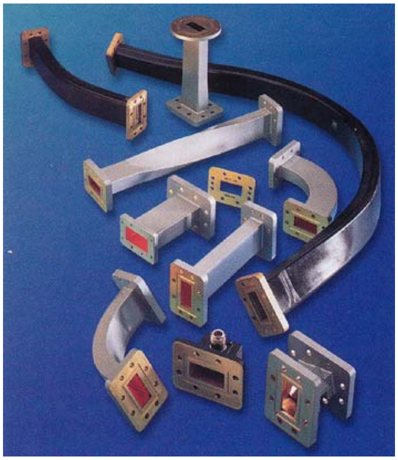
Install the connector for the top end of the waveguide before hoisting. It is much easier to do this at ground level. Refer to Waveguide and Coax Connector Assembly on page 5-11.

At the equipment end, a flexible jumper (waveguide or coax) is normally used to connect the radio to the waveguide in the overhead cable tray. It is at this jumper/ waveguide junction that the dehydrator connection is made for pressurization of the waveguide. Refer to Pressurization Equipment and Installation on page 5-21 for details.

Table 5-1 provides guidelines for waveguide hoisting, running, and fastening.

Table 5-1. Waveguide Hoisting, Running, and Fastening Guidelines

Task	Guidelines
Planning the route	• Use existing cable support runs and trays, where possible. • Run adjacent to other waveguide or coaxial cables, except where their routing is poor. • Do not run the waveguide adjacent to the tower ground wires or electrical services cables. • Select a route that is unlikely to be damaged by riggers, or that restricts their movement on the tower. • Do not run the waveguide along the topside of cross-members (to avoid it being stepped on). • Do not run the waveguide along the tower legs (these are the primary attachment points for pipe mounts). • Ensure there is adequate physical protection for the waveguide at locations where ice fall from towers may occur.

Task	Guidelines
Hoisting and Running	• Mount the waveguide drum on jacks and place at the base of the structure so that the waveguide is paid off from the bottom of the drum. • For long lengths of waveguide, fix a pulley block to the structure above antenna level, and thread a rope for hoisting. • Attach the rope to the waveguide using a hoisting grip, or with a secure series of half hitches, and carefully hoist the waveguide into position, while guiding it along the waveguide run.
CAUTION	Position sufficient personnel on the tower and at the drum to ensure the waveguide is fed carefully around possible obstructions and bends.
	• Carefully bend and twist the waveguide so that the connector can be offered up to the antenna flange without residual stress on the flanges. Fit the pressurizing seals (without using silicone grease) and bolt the two flanges together using the fixing kit provided. • The flexibility of elliptical waveguide allows it to be formed, with due care, around tower members and obstacles. Minimum bending radius for the E and H planes, and maximum twist figures (degrees per m/ft) will be specified in the datasheet for each waveguide type/size and must not be exceeded. E and H plane bending tool kits should be available from the waveguide manufacturer for each waveguide size, and their use is recommended. • For difficult sections, E or H plane bends or twists, or flexible waveguide may need to be used. These should only be installed as a last resort bearing in mind their cost and extra installation effort. **Figure 5-1.** Typical waveguide components: flexible waveguides, E & H bends, twists and a Type N transition 

Task	Guidelines
Fixing	• Holes must not be drilled in any mast or tower steelworks unless authorized by the tower owner in writing. • The waveguide must be supported by hangers sized to the waveguide and with an adaptor (clamp) suited to the structure. Typical hangers and adaptors are shown in Figure 5-2. Other fastening systems are available and include quick-fit (snap-in) types and stackable arrangements. • Check the waveguide datasheet for maximum hanger spacing. Recommended spacings depend on waveguide size, maximum wind speeds and whether or not radial ice loading is experienced at the site. For example, an elliptical waveguide sized for 7.5 GHz operation may have a maximum spacing of 1.5m (5 ft) where wind peaks are lower than 135 km/h (85 mph) and no ice, down to 0.6m (2 ft) spacing for wind peaks of 240 km/h (150 mph) and 25mm (1”) radial ice. • Ensure the waveguide cannot flex in the wind. Where necessary use rod supports. This may be especially applicable to the traverse between the tower and antenna. • For waveguide and pressurizable air-dielectric feeders the connector should be fastened to the antenna flange/connector but not weatherproofed until after the feeder is purged, which will be performed on termination of the feeder at the building end and installation of the pressurization system. The reason for this is that the air plug at the antenna-end connector must be removed in the purging process. Refer to Dehydrator Installation on page 5-25. • Use an appropriate wall feed-through where the waveguide enters the equipment building. The gland around the cable should provide a water, dust and vermin proof seal. Single and multiple waveguide/cable types are available. • If there is potential for water to enter a building on the waveguide where it passes through a wall feed-through assembly, provide a slight drip loop (sag) in the waveguide prior to entry, or run the waveguide at a slight uphill angle to the building.

Figure 5-2. Typical hanger and adaptor items

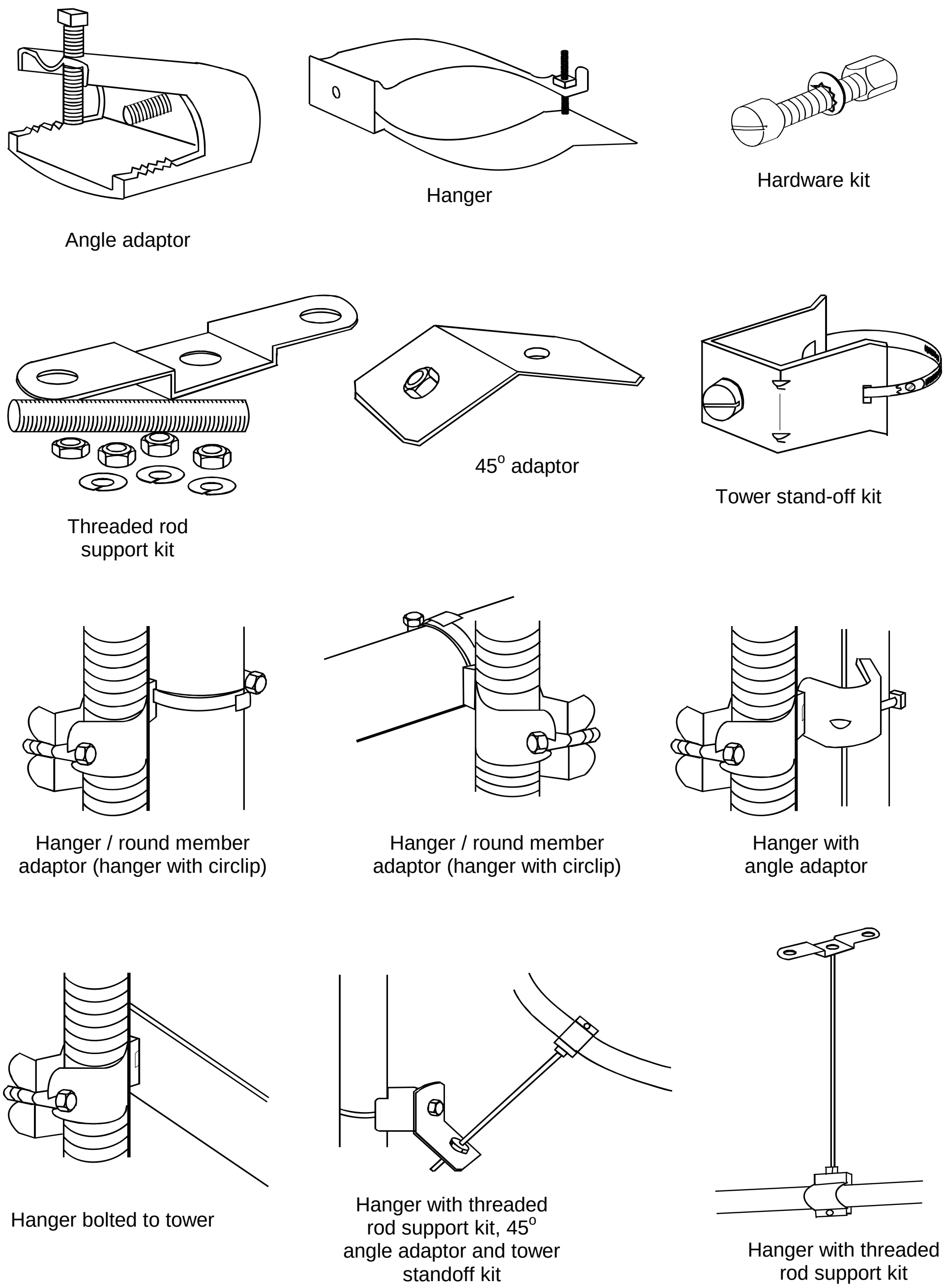


Figure 5-3. Typical wall feed-through accessories

Waveguide and Coax Feeder Grounding

Waveguide and coax feeders must be properly grounded to help prevent equipment damage due to lightning strikes. Additionally, coax feeders must be fitted with an appropriate lighting surge suppressor to limit the magnitude of the strike induced voltage difference between inner and outer conductors.

For lightning protection and site grounding requirements, refer to Chapter 6.

Unless otherwise specified by the customer, the feeder must be grounded at the following points:

- At the top of the tower, at the point where the feeder branches off to the antenna.
- At the base of the tower where the feeder branches off to the equipment building.
- At the point of entry to the building.

Where the feeder run on tower exceeds 30 m (100 ft), a grounding kit must be fitted at not more than 30m intervals or a split thereof. For instance, if the vertical run is 45 m, a grounding kit should be installed at the mid-point.

Grounding kits will be supplied by, or be available from the equipment or waveguide/cable supplier. Ensure the correct kit is used.

Feeder Grounding Guidelines

Always follow the instructions included with the grounding kit.

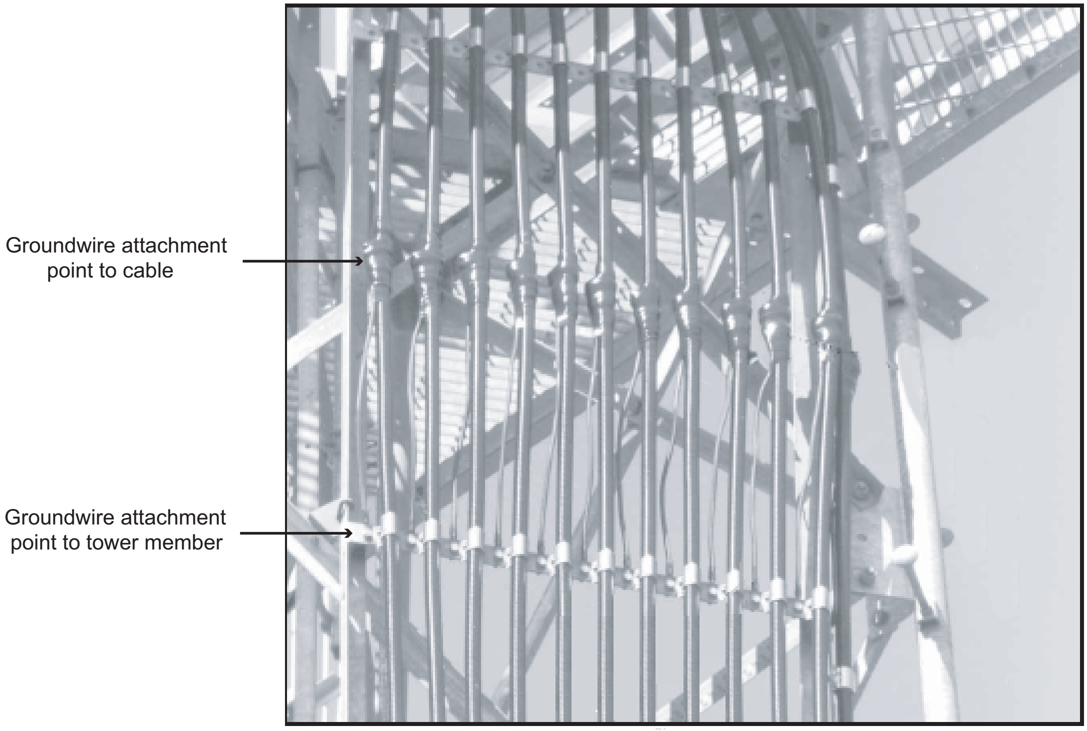
General considerations are:

- Where possible, the ground wire must connect to the tower or structure at a sharp downward angle.
    - The ground wire must not be installed at an upward angle.
    - The ground wire must not be looped or spiralled. Lightning takes the shortest path to ground.
    - If the ground wire is supplied with a crimped lug and the wire is too long for a correct installation, cut the lug off, trim the wire to length and attach a new crimp lug.
- The tower/structure end of the ground wire is normally bolted to a clamp such as an angle adaptor, or to a purpose fitted ground bar. Before fastening the clamp, scrape any paint or oxidation from the tower points of contact to ensure there will be a good low-resistance contact. Afterwards, liberally apply zinc-rich paint or conductive grease around the clamp to provide protection against corrosion.
- At non-standard installations such as building tops or sides of buildings, follow the same general guidelines but where proper grounding points are not provided these must first be installed.

CAUTION

Do not fit grounding kits during rain. To fit the kit a small section of outer sheath must first be removed to expose the outer conductor. All moisture must be kept from the attachment point until the kit has been attached and weather-proofed.

Figure 5-4. Example of feeder grounding on a tower



Waveguide and Coax Connector Assembly

This section provides guidance on the selection and fitting of connectors to waveguide and to foam and air-dielectric coaxial cables.

Manufacturer's instructions for connector assembly will be provided with all waveguide, and air and foam dielectric coax connectors. Equipment user manuals should also have instructions. These instructions must be followed for correct installation.

Selection

The choice of connectors will be determined by the antenna flange at one end and the equipment flange at the other. In the majority of installations there will also be a jumper fitted at the equipment end to provide a flexible connection from the waveguide or coax to the radio fitted in a rack. For waveguide and air-dielectric coax, this junction will also provide a connection point for the dehydrator pressure line.

While it is standard practice to terminate the top waveguide or coax connector

directly to the antenna flange/connector, in some instances a flexible jumper may also be required at this point to skirt past obstructions.

Connector attachment onto waveguide is specific to each manufacturer. Always source waveguide and connectors from the same manufacturer.

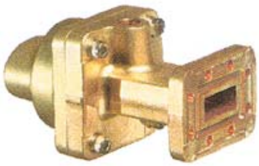
Waveguide Connectors

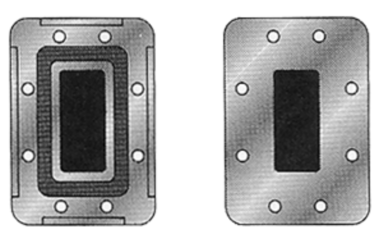
Table 5-2 gives general information and guidelines for connectors used with elliptical waveguide.

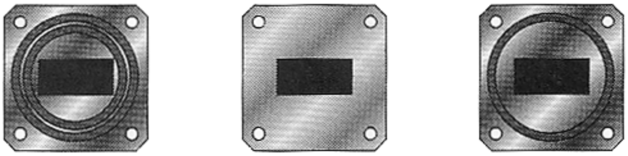
Table 5-2. Waveguide Connector Guidelines

Connector	Guidelines

General	• Connectors are tapered or multi-step transitions from elliptical to rectangular waveguide and mate with industry standard rectangular waveguide flanges
	• Connectors include a flange gasket, flange hardware (nuts and bolts), at least one pressure inlet with a 1/8 inch female pipe thread, and assembly instructions.
	• Non-tuned, tunable and fixed tuned connectors are available, depending on the waveguide type. For some waveguide selections there will be a choice of connector type, such as fixed tuned or tunable:
	  • Non-tuned connectors have a tapered transition and are recommended for use with standard grade elliptical waveguide.
	  • Tuned connectors have a tapered transition plus tuning screws, and are recommended for use with premium grade elliptical waveguide, with the tuning permitting optimization of (low) VSWR.
	  • Fixed tuned connectors have a stepped transition to provide a low VSWR over a broad bandwidth and are recommended for use with standard or premium grade elliptical waveguide.
	  • Non-tuned connectors are lowest-cost followed in order by fixed-tuned and tunable types

Connector	Guidelines
General (Cont)	**Figure 5-5.** Example tunable (top) and fixed tuned connectors   • Connectors are normally constructed of brass or plated aluminium. Fixing hardware is stainless steel.
Flanges Types	• Connectors are manufactured with flanges to comply with either the EIA (Electronic Industry Association of America), MIL (US military) or IEC (International Electrochemical Industry) standards. EIA, MIL and IEC flanges are generally compatible, but not identical. There can be slight variations in dimensions, tolerances, gasket style and thickness, alignment pins and bolt holes. Check manufacturers' catalogs for compatibility details. • Standard EIA and MIL flanges use American threads; IEC have metric threads/hardware. • There are three basic types of flange, unpressurizable contact, pressurizable contact, and pressurizable choke/cover. These three types are not compatible/interchangeable. *The pressurizable contact type is the industry standard for point-to-point digital microwave applications*.
Unpressurizable Contact Flanges	• CMR and UER series contact flanges are not pressurizable and do not require gaskets. CMR flanges are always rectangular in shape, have alternate tapped and clear holes and are secured with bolts only. The UER flanges are also always rectangular but have all clear holes and are secured with nuts, bolts and washers.

Connector	Guidelines
Pressurizable Contact Flanges	• Pressurizable contact flanges are available in EIA, MIL and IEC codes. They are always rectangular, and as CPR and MIL are available as grooved or ungrooved. IEC (PDR series) is grooved only. • EIA CPR G series and equivalent MIL UG series flanges have a gasket groove and are supplied with a full thickness gasket for mating with other CPR G or UG *grooved* flanges. When mated with an un-grooved CPR-F or UG flange, a half-thickness gasket is required, which may need to be separately ordered. When mated with a PDR flange a half-thickness gasket must be used in conjunction with the supplied PDR gasket. • IEC PDR series include a gasket groove and mate with another PDR using the supplied two gaskets. Compared to CPR G flanges, the PDR gasket grooves are deeper and use a different gasket. When mated with a CPR G flange a half-thickness CPR gasket must be used in conjunction with the PDR gasket. • The CPR F series and equivalent MIL UG series are not grooved and are intended for mating with a CPR G series or equivalent grooved UG flange, where a half thickness gasket must be used in instead of the full-thickness gasket supplied with the CPR G or UG grooved. A CPR F can be mated with another CPR F but requires a special seal. • Care must be taken when mating between the same series or a different series to ensure the correct selection of gasket or combination of gaskets. Check the assembly instructions and/or manufacturers' catalogs for details. **Figure 5-6.** Example CPR G / PDR / UG grooved (left) and CPR F / UG un-grooved 

Connector	Guidelines
Pressurizable Choke/Cover Flanges	• Choke/Cover flanges are available in MIL and IEC codes. Depending on the waveguide size they are either rectangular or round and require gaskets for sealing. The choke flange gets its name from the 1/4 wavelength slot or groove in the face of the flange, which in combination with its relationship with the waveguide opening is designed to provide cancellation of any RF leakage at the join. Choke flanges have application where RF leakage must be kept to an absolute minimum, and in feeders for high power transmission where any discontinuity might result in arcing across the gap. • CBR, CAR and UG equivalent **choke flanges** include a gasket groove, choke, and tapped holes for mating with cover flanges or cover/gasket flanges. Two choke flanges cannot be mated. • UBR, UAR and UG equivalent **cover flanges** have no gasket groove and have clear holes for mating with a choke flange, cover/gasket flange or with another cover flange. Where two cover flanges are mated a special gasket is required for pressurization. • PBR and PAR **cover/gasket flanges** include a gasket groove and have clear holes for mating with cover flanges, with other cover/gasket flanges, or with choke flanges. When mated with a cover flange a single gasket is required. When mated with another cover/gasket flange or with a choke flange, a double gasket is required. **Figure 5-7.** Example choke (left), cover (middle) and cover/gasket flanges  • Pressure windows are used to provide an air tight seal where needed in the waveguide feeder. In a typical installation a pressure window will be installed at the elliptical/flex-twist waveguide junction within the equipment building. Pressure windows do not normally have gasket grooves but may be supplied with a half thickness gasket for use in place of a full thickness gasket supplied with the likes of the CPR G series flange. • Waveguide to coaxial adaptors are available to provide a transition from one feeder type to the other.

Coax Connectors

This section contains general information and guidelines for coaxial connectors typically used on antenna feeders for all-indoor microwave radios on bands 300 MHz to 3 GHz.

Background Data on Connector Types

- The Type N 50 ohm connector was designed in the 1940s for military systems operating below 5 GHz. The Type N uses an internal gasket to seal out the environment, and is hand tightened. There is an air gap between center and outer conductor. In the 1960s, improvements pushed performance to 12 GHz and later, mode-free, to 18 GHz. Type-N connectors follow the military standard MIL-C-39012.
- The 7/16 DIN connector was developed in Germany during the 1960s for high-performance military applications. It enjoys a number of technical advantages over the type N interface, notably intermodulation performance is more stable because of its higher contact pressure, greater coupling torque and robust design. Mating is easier, and once mated it has greater resistance to environmental forces. The 7/16 DIN can also be used at higher power levels without degrading connector performance.

For the specialist foam and air-dielectric coaxial cables manufactured by Andrew, Radiowave, RFS, and others, connector attachment onto such coax is generally specific to each manufacturer. For specialist cables always source the cable and connectors from the same manufacturer.

Connector Assembly Guidelines

Connector assembly must be carried out in accordance with the connector manufacturer’s instructions. With few exceptions (such as bulk supply of BNC, TNC and Type N connectors for general purpose use with internationally standardized coax), all connectors should be accompanied by an assembly instruction sheet.

CAUTION

If assembly instructions are not supplied and there is any doubt as to the procedure required for correct assembly, check with the radio system supplier or the connector/cable supplier. Correct assembly and weatherproofing is vital for the long term integrity of a radio system.

If it is a first-time assembly, doing a trial preparation and assembly is a good idea. In doing so do not complete an irreversible step unless a reattachment kit or spare connector is available.

Connector Guidelines at Antenna End of Feeder

Always fit connectors in accordance with manufacturer's instructions.

In general:

- Fit the antenna-end connector before hoisting.
- Do not prepare the cable and fit the connector in wet weather. All moisture must be kept out of the assembly.
- With waveguide and air-dielectric coax connectors, ensure no cuttings fall into the mouth of the waveguide/coax.
- After assembly and prior to hoisting and mating, protect the connector from ingress of rain and dust. Waveguide and the specialist foam and air-dielectric connectors will be supplied with plastic protective caps for this purpose.
- If during assembly grease and/or dirt are deposited on the surface of the connector and the immediately adjacent 100mm (4 in.) of cable/waveguide, ensure it is cleaned off prior to mating and weatherproofing. Unless surfaces are clean and grease-free, weatherproofing tapes will not properly bind to provide a weatherproof seal. If grease is present use a clean alcohol damped cloth to remove all traces
- For waveguide and pressurizable air-dielectric feeders the connector should be fastened to the antenna flange/connector once hoisted into place, but not weatherproofed until after the feeder is purged, which will be performed on termination of the feeder at the building end and installation of the pressurization system.

Purging the feeder requires removal of the air inlet connector at the antenna end of the feeder. Do not weatherproof the top connector until after the feeder has been purged.

Connector Guidelines at Building End of Feeder

With jumpers

Most installations will require a jumper to provide the flexible access needed to branch down from an overhead cable tray or similar, into an equipment rack and onto the radio.

- For waveguide installations the jumper may be a length of flex-twist waveguide or fixed rectangular waveguide with E and H bends, or a combination thereof.
- For coax feeders the jumper cable will be a short length of more flexible coax, such 1/2-inch coax connecting to a main feeder of 7/8-inch or 1 1/4-inch coax.

Without jumpers

Where the waveguide or coax feeder has the flexibility needed for this purpose, it can be directly terminated onto the radio. However, before committing to this consider the following:

- Waveguide feeders must be pressurized, which means the building-end connector must be accessible for this purpose. The connector interface must also be fitted with a pressure window. If this connector is attached directly to a radio, then in the event the radio or its RF head is replaced then all pressurization in the feeder will be lost. Terminating the waveguide in the overhead cable tray and using a jumper (unpressurized) gets over this concern. It will also usually provide easier access for the pressurization tubing and, if required, better access to tune screws for tunable connectors. The negatives are that the jumper will have a slightly higher attenuation compared with an equivalent length of the main waveguide, and each additional connector will contribute slightly to the overall VSWR figure and cost.
- Coax feeders must be fitted with a lightning surge suppressor at the building end, normally at the point of entry to the building. This junction provides a convenient connection point for a jumper cable to the radio. The only negative is that the smaller diameter (more flexible) cable will have a higher attenuation figure compared to a comparable length of the main feeder coax, though for the jumper lengths normally required (2 to 10m), the additional attenuation will be small, typically less than 1 dB. Also remember that if the main feeder is air-dielectric coax and requires pressurization, then access for the pressurization tubing will be needed at the connector.

General Connector Assembly Guidelines

To fit a connector:

- Fit the connector in accordance with the manufacturer’s instructions.
    - Use the appropriate cut-off and strip-back tools where recommended. These will provide a much more accurate cut and reduce the likelihood of unwanted cut damage.
    - Ensure the outer conductor is not scored when the sheath is cut. Scoring will reduce the strength of the outer, which may cause the outer to crack or break when the feeder is flexed.
- Ensure that when cutting and trimming waveguide or air-dielectric coax that no cuttings fall into its mouth.
- For waveguide and pressurizable air-dielectric connectors at the building end:
    - Remove the air inlet plug and replace with a Schrader valve or other pressure connector provided. Use PTFE tape around the thread to ensure an air tight seal.
    - Ensure the correct gasket or gaskets are used in the mating and that the pressure window has its pressure side on the feeder/antenna side of the transition.
- Where crimp connectors are being used with solid coax, ensure the correct crimp tool is used. Use of general purpose crimp tools may result in an unsound installation with physical connections that may deteriorate over time.
- Where a connector is to be re-used, a re-attachment kit may be recommended or required. This particularly applies to waveguide and to foam and air-dielectric coax connectors.
- All weather-exposed connectors must be weatherproofed. For general guidance on connector weatherproofing refer to Weatherproofing Connectors on page 4-13 in Chapter 4.

Waveguide and Coax Feeder Testing

For elliptical waveguide and coax feeders a return loss measurement is recommended. If possible the measurement should be at the radio attachment point to include the complete feeder run and antenna. The measurement data will confirm the integrity of the feeder and antenna installation and provide a valuable reference for any future maintenance action where the feeder or its antenna is suspect.

The most complete and convenient measurement solution is provided by a handheld, battery operated, microwave transmission line analyzer, which includes measurement of return loss, feeder loss and distance to fault (discontinuity). An optional power meter for power measurement is available with some instruments. Test data can be saved to file for future reference. Figure 5-8 shows an analyzer with a 3 to 20 GHz capability. Accessories include a range of cables and adaptors to connect to waveguide or coax connectors.

Figure 5-8. Example portable test set

Other measurement solutions for a return loss measurement include a network analyzer, or a power meter in conjunction with a directional coupler.

- A purpose designed transmission line analyzer and some network analyzers provide an ability to frequency sweep a feeder and its associated antenna.
- A power meter and directional coupler provides a measurement just at the operational frequency; it uses the radio transmitter to provide the test signal. However the combined cost of a power meter and coupler is considerable less than an analyzer.

For a Return Loss to VSWR conversion chart, refer to Appendix C.

Pressurization Equipment and Installation

Waveguide and air-dielectric feeders must be pressurized with a constant supply of dry air to reduce the risk of corrosion caused by accumulated moisture through minor leaks and condensation, and to reduce the risk of voltage breakdown (arcing) where high transmit powers are used. Moisture laden air also increases VSWR and therefore impacts signal quality. Feeders are normally pressurized to between 21 kPa (3 lb/in^2) and 55 kPa (8lb/in^2).

The exceptions to pressurization are:

- Where short runs are involved (less than 4m, 12ft) and the volume is small (less than 28 liters, 1 cubic foot), a *non-pressurized desiccator* system can be used.
- For low power point-to-point split-mount systems where the ODU is connected to the antenna via a short length (max 1m) of flex-twist or rectangular waveguide (remote mount ODU), no pressurization is required. However connector seals must be fitted and flanges weatherproofed as normal.

Dry air supply and pressurization systems can be categorized as static or dynamic:

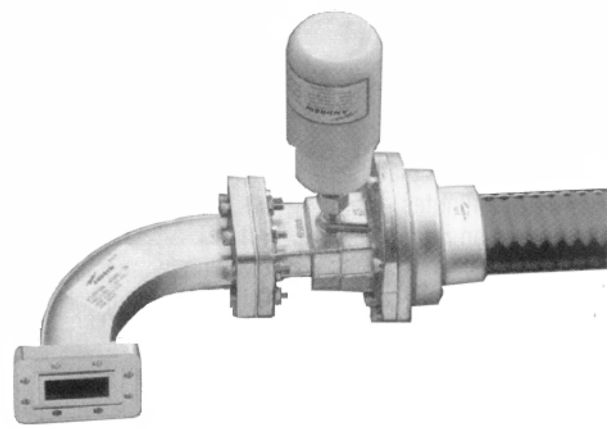
Static Systems

Static systems can be unpressurized or pressurized, but do not supply dry air on demand. They are not powered and provide no alarm interface to signal when a replacement or a desiccant recharge is needed, so must be inspected on a routine basis for maintenance.

Non-pressurized Desiccator

The non-pressurized breathing desiccator is a canister filled with a silica gel desiccant, through which air is forced out of or into as the feeder pressure changes against atmospheric pressure. As the feeder pressure decreases, incoming air passes through the desiccant, which absorbs the moisture. Static desiccators are available with capacities to last many months on a small tight system of 28 liters (1 cubic foot) or less. They are normally direct-mounted on a feeder connector via its 1/8 in. NPT pressure fitting, or where no pressure fitting is provided, through a purpose fitted pressure inlet. They are typically used to ensure dry air for very short feeders and for air-dielectric antenna feeds and/or combiners at the end of a foam feeder. Breathing desiccators are normally disposable and inexpensive to spare. Refer to Figure 5-9 on page 5-22.

Figure 5-9. Example static desiccator installation



Pressurized Hand Pump Systems

Pressurized hand pump systems are lightweight, portable air drying systems where removal of moisture is accomplished by pumping air into the feeder via a silica gel desiccant. They are suitable for small, tight systems with a volume of 280 liters (10 cubic feet) or less. The desiccant can be regenerated by baking it in an oven at 170°C (350°F) for approximately four hours, when the color will change from amber (exhausted) to blue (regenerated). Figure 5-10 shows an example hand pump.

Figure 5-10. Example hand pump

Dynamic Systems

Dynamic systems incorporate a pressurizing source that provides dry air or gas on demand.

An AC or DC powered air compressor is the most widely used pressurization source. Compressor systems are available with dehydration based on silica gel, or on a membrane / heat exchanger. The silica gel types are also available with manual or automatic regeneration of the silica gel. The membrane types are fully automatic. These systems are normally supplied with a basic installation kit, which should include a length of polyethene tubing, shut off valve, and a 1/8” NPT inlet connector.

An alternative to a powered dehydrator is a nitrogen cylinder system, which introduces nitrogen automatically to the waveguide via a pressure regulator.

Manual Regenerative Dehydrators

Manual regenerative dehydrators use a silica gel canister as the moisture removal agent, which must be manually replaced or regenerated when exhausted.

Regeneration is achieved by baking the silica gel in an oven at 170°C for approximately four hours. If sized correctly for the feeder and there are no abnormal air leaks, regeneration servicing can be at six to twelve month intervals.

They are available with and without alarm outputs to signal low pressure, continuous running, high moisture content (humidity), and power failure. Figure 5-11 shows a typical manual regenerative dehydrator for volumes up to 280 liters (10 cubic feet).

Figure 5-11. Example small-volume manual regenerative dehydrator

Automatic Regenerative Dehydrators

Automatic regenerative dehydrators typically use two silica gel canisters, with one on line and the other on standby or regeneration. When the online canister is exhausted it is automatically replaced by the alternate unit and its contents regenerated by heating and backwashing with a reverse dry air flow.

They are normally available with alarm outputs for under and over pressure, continuous running, high moisture content (humidity), and power failure. Being fully automatic, regenerative dehydrators are virtually maintenance free. They are available in various capacities to service volumes up to 50,000 liters (1,800 cubic feet).

Membrane Type Dehydrators

Manual type dehydrators use a heat exchanger and permeable membrane to remove moisture from the air. They are normally available with alarm outputs for under and over pressure, continuous running, high moisture content (humidity), and power failure. They are virtually maintenance free and available in various capacities to service volumes from 280 liters (10 cubic feet) to 70,000 liters (2,500 cubic feet). Figure 5-12 shows two examples of membrane type automatic dehydrators for volumes up to 560 liters (20 cubic feet) and 2200 liters (80 cubic feet).

Figure 5-12. Example small and medium volume automatic membrane type dehydrators

Nitrogen Pressurization Systems

Nitrogen pressurization systems use nitrogen cylinders connected to the feeder via a pressure regulator to maintain the required pressure. They have application for small tight systems where there is no ac power to the site. There are no moving parts, but the cylinder must be replaced when the pressure can no longer be maintained. A cylinder and system pressure alarm should be installed to indicate when the pressure is getting low.

Dehydrator Installation

Installation must be in accordance with manufacturer's instructions.

Static Dehydrator Connection and Purging

The following are general guidelines for Static Dehydrator connection and purging:

1. Check that a pressure window has been installed at the waveguide connector junction and that a Schrader (non-return) valve has been fitted to the 1/8 NPT inlet, using PTFE tape to ensure a good seal
2. Connect a dry air hand pump or portable dehydrator to the Schrader valve.
3. Purge the waveguide by pressurizing it to 35 kPa (5 lb/in^2) and then releasing the pressure by opening the air plug on the connector *at the antenna end.*
4. Close the air plug at the antenna end and repeat step 3 twice more. This purging process removes all moist air, replacing it with air from the hand pump, which includes a silica gel canister in its air path.
5. Pressurize the waveguide to 35 kPa and remove the hand pump.
6. Fit a pressure gauge assembly and note its reading.
7. If practical check the system for leaks by applying liquid detergent to all joints and connections and check for bubbles, which indicate leaks. Thorough checking is particularly important for static-pressurized systems.
8. Re-check the pressure again after one hour, when there should be no observable change in the reading.

If there has been significant change in outside air temperature or sun to shade during this time, the air temperature within the feeder and hence pressure will alter as a result.

9. If a breathing type static desiccator is to be installed, remove the Schrader valve after purging the system and screw in the breathing desiccator.
10. Weatherproof the *antenna end* connector. Refer to Weatherproofing Connectors on page 4-13 in Chapter 4.

This completes the purging and the feeder can be used for service.

Dynamic Dehydrator Connection and Purging

The following are general guidelines for Dynamic Dehydrator connection and purging:

1. Establish the routing of the polyethylene tubing from dehydrator to connector and provide support as necessary.
2. Check that a pressure window has been installed at the waveguide connector junction.
3. Install the pressure inlet coupling to the connector using PTFE tape to ensure a good seal.
4. Connect the designated dehydrator alarm(s) to the alarm input(s) on the radio. This may be a single dehydrator master alarm or multiple alarms such as low pressure, continuous running and power failure.
5. Follow the dehydrator system start-up and test procedures given in the manufacturer's operators manual. Ensure the dehydrator has been set for the correct on/off pressures, usually between 21 kPa (3 lb/in^2) and 55 kPa (8lb/in^2).
6. Purge the waveguide by pressurizing it to the designated pressure (dehydrator motor stops) and then releasing the pressure by opening the air plug on the connector *at the antenna end.*
7. Close the air plug at the antenna end and repeat step 6 twice more. This purging process removes all moist air, replacing it with dry air from the dehydrator.
8. Check the feeder system for air leaks. This is best done with a pressure meter on line and checking for any pressure change over one hour or more.
9. Weatherproof the *antenna end* connector. Refer to Weatherproofing Connectors on page 4-13 for weatherproofing guidelines.

This completes the purging and the feeder can be used for service.

Chapter 6. Lightning Protection and Site Grounding Requirements

This chapter provides information and recommendations on lightning protection and site grounding. As well as preventing damage, correct installation of protection devices and proper grounding is normally a requirement for equipment warranty purposes.Topics include:

Use of appropriate lightning protection devices and correct site grounding are related issues. One cannot be considered in isolation of the other.

The Harris Stratex Networks' equipment warranty requires correct protection and grounding practices. Harris Stratex reserves the right to exclude from warranty the repair or replacement of lightning damaged equipment from non-complying installations.

For a site grounding and lightning protection checklist, refer to Appendix B.

Overview

One of the primary causes of premature equipment failure is lightning damage due to incorrect protection practices. For point-to-point microwave the failure modes that stand out are:

- **Incorrect Grounding Practice.** When a site is struck by lightning incorrect site grounding can cause voltage differences and current flows that can result in catastrophic equipment failures.
- **Excessive Voltage Between Coax Inner and Outer**. This is relevant to the IDU/ODU cable of split-mount systems and to all-indoor radios using a coax feeder. A lightning induced current pulse on the center conductor can result in a voltage difference between inner and outer conductors of a magnitude sufficient to destroy components and PCB tracks at and around the cable interface. Dependant on whether the interface circuit offers a high or low impedance to the pulse, the breakdown will be due to over-voltage or excessive current flow - or both. To protect against these effects, proper installation of a suitable lightning surge suppressor, or suppressors, is essential.
- **Inadequate Primary Protection**. This refers to protection on incoming telco and power lines and is particularly relevant to overhead lines; lines which are prone to lightning strike.

Lightning Characteristics

A lightning strike is a short duration high energy event. Studies have shown that the average lighting strike waveform has a one to two microsecond rise time, and a current stroke of 18 kA to 20 kA with a time to half peak current of 45 to 50 microseconds. Even though lightning strikes are direct current (dc) events, because of the rapid rise time they also contain a great deal of high frequency energy, which may span 100 kHz to 10 MHz.

Damage at Tower Sites

Because they point higher than the surrounding terrain and other nearby structures, tower sites are frequently struck by lightning. When struck, the voltage drop from the top to the bottom of the tower can be extremely high.

As an example, the combined direct current and inductive voltage drop across a 50 m (165 ft) tower from an average lightning strike of 18 kA can be over 360 kV.

Unless bonded to the tower, coaxial cables and waveguide installed on a tower struck by lightning will still be at a low voltage potential compared to the tower at the instant of a strike causing a high voltage potential across the cable insulating sheath, which can cause voltage breakdown of the sheath material (pin holing). For this reason feeder and IDU/ODU cables must be grounded to the tower at the top, at the cable pull off point (departure of cable towards the equipment building), and at no more than 25 m to 30 m intervals (80 to 100 ft) on the tower.

Most tower sites route coaxial cables and waveguide from tower to the building entrance, at about 3 m (9 ft) above the tower base. At these heights the voltage potential generated by a lightning strike on a tower (and the cable shield bonded to it), can be 75kV or more when compared to the voltage at the base of the tower. This is the source of most of the damaging lightning energy directed towards the equipment inside the building. While this energy can be significantly reduced by bringing the cables off the base of the tower and routing them at or below ground level to the building, this is not always practical. To mitigate the effects of this surge energy, proper site and feeder grounding is essential.

Ground System Requirements

This section describes the following topics:

- Site Grounding
- Measurement of Ground Resistance
- Single Point Building Grounding
- Rack Grounding
- Multipoint Building Grounding

Site Grounding

Proper site grounding disperses the energy of a lightning strike such that on-site personnel are not harmed and equipment is not damaged.

A continuous ground system must interconnect all site grounds, ideally with a radial ground system at the tower, a perimeter ground around the equipment building, and a single interconnect point for the tower and perimeter grounds at the base of the cable-entry master ground bar (MGB). This will disperse lightning energy into the earth most effectively and ensure ground voltage differentials at the site are kept to minimum levels.

Site grounding is an extensive subject, one which must be addressed as a part of the civil works associated with the construction of a tower/mast, equipment building and the provisioning of ac power. For new sites or where existing sites have a history of equipment being damaged by lightning strikes, a company specializing in lightning protection services and site grounding should be consulted.

Measurement of Ground Resistance

Ground resistance should be checked during the pre-installation site survey, and confirmed at commissioning.

Measurements most often required are:

- Continuity Test
- Ground Connection To Earth

Continuity Test

A continuity test checks the effectiveness of ground wires and their bonding. Measurements are usually measured from a reference ground conductor, such as the master ground bar. For continuity tests a DVM can be used provided it has the measurement resolution needed to properly measure fractions of 1 ohm.

Ground Connection To Earth

This ia a check of the effectiveness of a ground connection to earth, which for the site/tower ground should be less than 5 ohms. The most reliable method is a 3-point test, based on the IEEE Standard 81-1983. It references three points of earth contact; the ground conductor under test, and two probes inserted into the ground at an appropriate distance, one a current probe, the other a potential probe. However, for good accuracy, the 3-point test requires the ground conductor to be isolated from the equipment and /or tower, which in most instances will not be permitted for an operating site. Figure 6-1 shows a test set for continuity testing and for two, three, and four point ground testing[1].

Grounds must not be disconnected at operational sites. The ac mains ground must not be disconnected except by a registered electrical engineer authorized by the site owner/operator.

Figure 6-1. Example of a continuity and ground tester, with accessories

In situations where a three point test is not possible, a clamp-on resistance tester is recommended, providing the ground wire/strap location and size permits clamp-on access. While not providing the same accuracy as a three point test, it does permit a quick and easily repeatable test for routine maintenance visits.

Figure 6-2 shows a clamp-on ground tester.

1 A 4-point test, is used to measure soil resistance. Such a check should be performed before site construction to help determine the most effective type and location of an earth grid and radials.

Figure 6-2. Example clamp-on ground tester

Single Point Building Grounding

Single point grounding has *all* equipment within the building at the same ground potential. This includes grounds for the mains and telco terminations into the building and for power supplies.

Optimum equipment grounding is provided by a single point ground using a master ground bar (MGB) at the feeder entrance point; the MGB is connected directly to the site/tower ground system using heavy gauge copper wire or strap. The wire size should not be less than 52 mm^2 (0 AWG).

Effective single point grounding will also be achieved where there are multiple ground connections into the building *providing* these grounds are directly bonded to a common perimeter ground for the building.

The MGB is the ground point for:

- All equipment within the building
- Service mains ground
- Telco ground
- Cable sheath ground
- Building-entry lightning surge suppressor (coaxial feeders)

A single point ground eliminates the potential for damaging voltage differences that would otherwise occur between different grounding points. In effect, with single point grounding the ground referenced voltage for all equipment in the building rises and falls at the same level as the strike induced voltage gradient passes through the earth, thereby removing the possibility of damaging currents

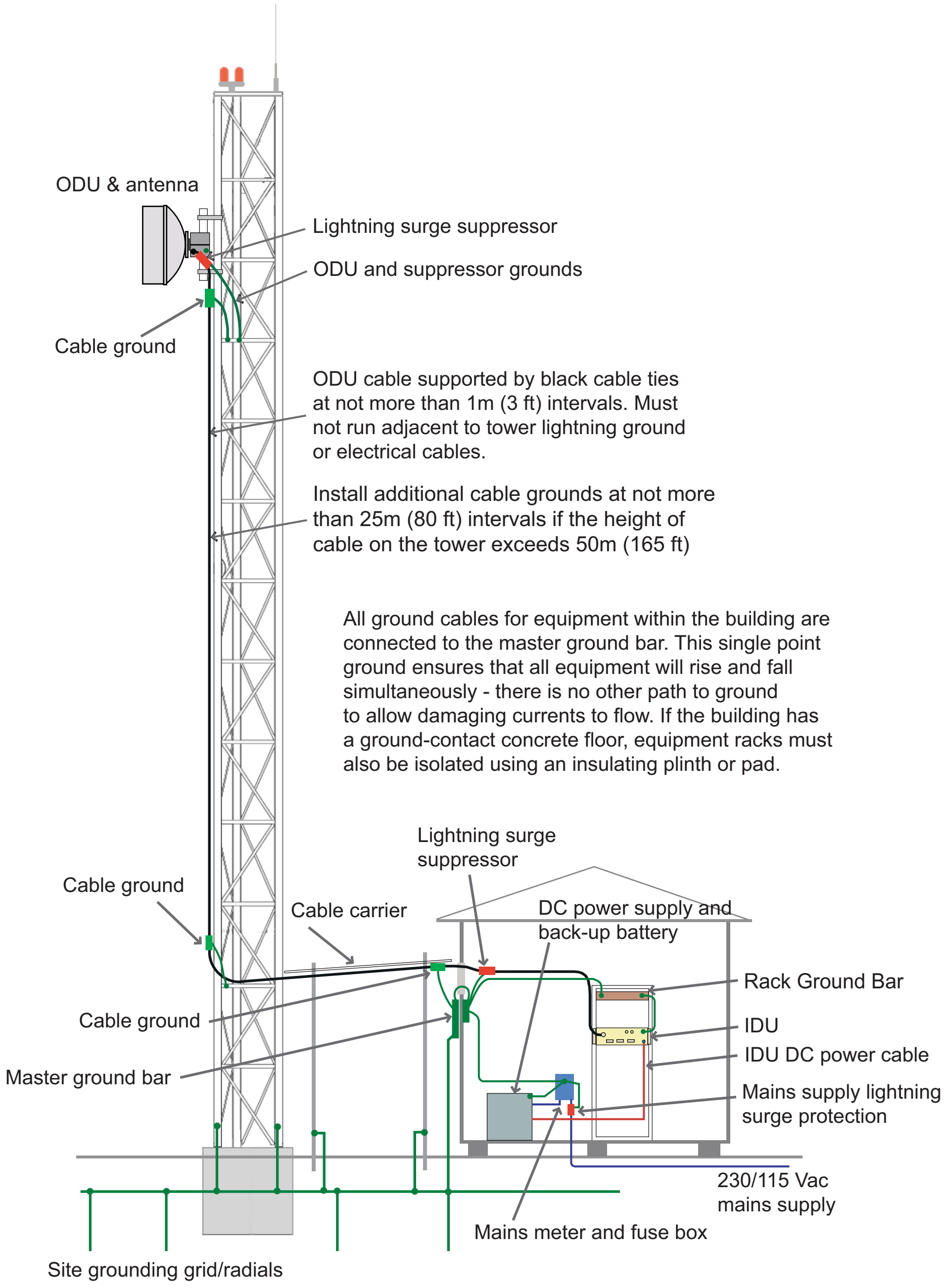
flowing between equipment.

CAUTION

If the building has a concrete floor in direct contact with the ground (ground poured concrete), all ground-connected equipment within the building must be isolated from the floor using insulating plinths or pads to avoid defeating the single point ground.

Figure 6-3 on page 6-8 shows an example of recommended grounding practice for a split-mount installation using single point grounding.

Figure 6-3. Example split-mount installation with single-point building ground



Rack Grounding

In order to dissipate currents caused by potentials between equipment in a rack, the rack must be grounded to the station MGB. The rack ground wire to the MGB must be a minimum of 16 mm^2 / 6AWG, and should be green/yellow PVC insulated, copper stranded wire.

- Ground wires must be kept as short as possible with no looping of the wire.
- Wire directly to the MGB, don't service-loop (don't just connect to another ground-wire connection on near-by equipment).

Do not connect the rack-to-MGB ground wire directly to the rack; terminate the ground wire to a ground bar located in the rack, and *individually* connect each item of equipment installed in the rack to the same rack ground bar. A rack ground bar will normally be installed at the top or bottom of a rack.

- When connecting each item of equipment to the rack ground bar, avoid stacking multiple ground lugs on a single ground bar connection. If it becomes necessary to replace equipment *and its ground wire*, and its ground lug is towards the bottom of the stack, other grounds must be disconnected to remove the needed one, which will disrupt ground connectivity to other equipment.

In order to maximize protection, all equipment connected to waveguide/coax from the tower must be installed in a rack close to where the waveguide/coax enters the rack, and the rack ground bar installed accordingly:

- If the cable(s) enter towards the top of the rack, such as with an overhead cable-tray installation, then the rack ground bar must be installed at the top of the rack and the radio equipment installed top-down in the rack.
- If the cable(s) enter low, such as with a raised floor installation, then the rack ground bar must be installed at the bottom of the rack, and the radio equipment installed bottom-up in the rack.
- Where a rack is fully populated with radio equipment such that waveguide coax cables terminate to radio equipment at all points in a rack, the rack ground bar must be installed where the cables enter the rack; at the top for top-entry, and at the bottom for bottom-entry.

Figure 6-4 on page 6-10 illustrates the effects of *incorrect* installation of a rack ground bar for top-entry coax. Any leak-through surge current must pass through the height of the rack to be returned to ground via the rack ground bar and MGB.

Figure 6-5 on page 6-10 illustrates the effects of *correct* installation of a rack ground bar for top-entry coax. Any leak-through surge current is returned more directly to ground rather than passing through the rack and installed equipment.

Note that if the rack is not isolated from other (non MGB) ground points there will be other possible current paths through the rack. This may occur where a rack is anchored-bolted to a ground-poured concrete floor, or other equipment in the rack is grounded via one or more different building grounds, such as to an ac mains supply ground, or a telco ground.

Figure 6-4. Incorrect location of Rack Ground Bar for Top-entry Coax

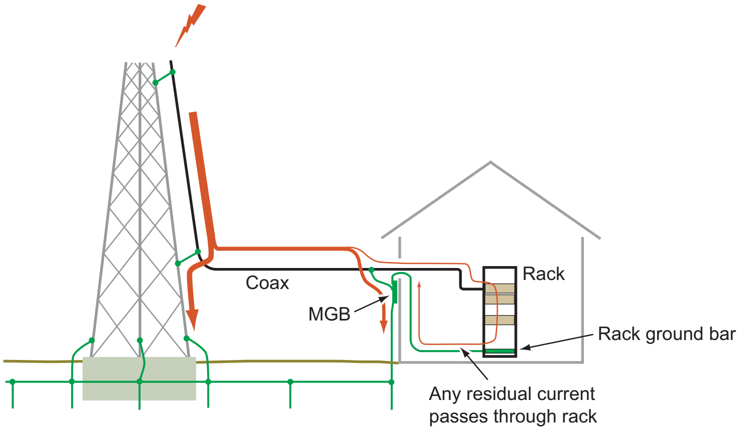
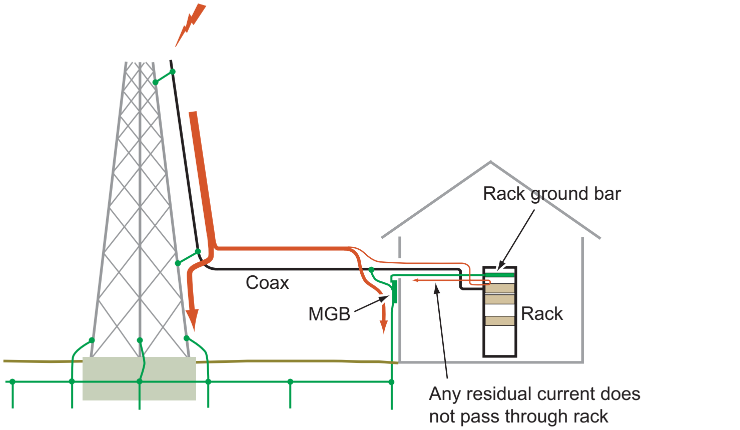


Figure 6-5. Correct Location of Rack Ground Bar for Top-entry Coax



Multipoint Building Grounding

Multipoint grounding is where the AC and/or telco grounds are *not* bonded to the site/tower ground. Instead their grounding is provided by separately installed ground rods or similar. With such an installation, strike induced voltage gradients in the ground can cause damaging current flows in equipment connected to the different ground points.

The primary objective at such sites is to reduce ground path impedance between the ground attachment points, between the equipment, and between the equipment and the grounds to minimize the magnitude of lightning induced voltage gradients between these points.

Refer to:

- Determining Whether a Building Is Multipoint Grounded
- Mitigating the Effects of Multiple Grounding

Determining Whether a Building Is Multipoint Grounded

While it may appear that different grounds come into a building, they may be connected to a common, buried, perimeter ground for the building, which connects directly to the MGB and the site ground system. If so, the building is considered to be single point grounded. The building/site records should confirm this. If not, the ground points can be checked by measuring the resistance between them when completely disconnected from equipment, when if the resistance between the different grounds is less than 1 ohm, it indicates a common perimeter ground. Refer to Measurement of Ground Resistance on page 6-4.

Mitigating the Effects of Multiple Grounding

At existing sites where a single point ground system has not been implemented[2] and cannot be cost-effectively introduced, the effects of a multiple grounded building can be mitigated by following these guidelines:

- Survey the building to determine what different external ground connections come into the building and how and where they may be interconnected.
  - A prerequisite is a properly installed ground bar at the cable entry point to the building, to which all incoming coax/waveguide from the tower is grounded. This ground bar must connect directly to the site/tower ground system.
  - Check AC power grounding and the grounding provided for incoming telco lines or similar, and if racks and other ground bonded equipment are anchor bolted onto a concrete floor, which has been poured directly onto ground.
- Different ground connections into the building must be directly bonded within the building using heavy gauge wire or copper strip (minimum 21 mm^2, 4 AWG).
  - The wire runs must be as direct as possible and connect between each point directly - do not connect in series. Bear in mind that what is needed is a ground-ring inside the building.

[2] The AC and/or telco grounds are not bonded to the site/tower ground. Their grounding is provided by separately installed ground rods or similar.

- Racks must be separately grounded from their ground bars to the cable-entry ground bar, using minimum 16 mm^2 6 AWG ground wire, and follow the same route as the feeder/ODU cables. Rack ground bars must be located at the top of a rack for top-entry feeder/ODU cables, or at the bottom for bottom-entry raised floor installations; refer to Rack Grounding on page 6-9 for guidance.
- Where adjacent racks are anchor-bolted to a ground-contact concrete floor, they must be electrically bonded between their bases using 16 mm^2 6 AWG ground wire.
- Check that all existing equipment installed in racks is correctly grounded to its rack ground bar. This is especially applicable to equipment that is to be connected to in the new installation, such as a mux other radios for a trib inter-connection.
- Check the effectiveness of all point-to-point ground cabling within the building using a resistance meter.
  - A resistance of not more than 1 ohm should be recorded between all points; typically it should be less than 0.5 ohms. (This resistance test is not intended to measure the resistance to earth, for which a three-point ground tester or clamp-on resistance tester should be used).

Lightning Surge Suppressors

This section provides information on lightning damage cause and effect, surge suppressor action and types, and suppressor installation. Refer to:

- Introduction
- Lightning Surge Suppressor Action and Types
- Suppressor Installation

Introduction

Lightning surge suppressors must be fitted into all coax feeders and IDU/ODU cables. For many suppliers, such as Harris Stratex Networks, their correct installation is a prerequisite for equipment warranty validation.

Harris Stratex Networks offers two warranty periods, a standard warranty of 15 months, or an extended warranty of 27 months. The 27 month warranty is offered where installations are performed by Harris Stratex personnel or their representatives. It is also offered to customer's wishing to do their own installations who have satisfactorily completed a Harris Stratex Best Practices training course.

- Correct installation of surge suppressors for a split-mount radio requires one suppressor installed at cable entry to the building, either directly inside or outside, and a second arrestor installed at the ODU. Having suppressors correctly installed at these two locations is a primary point of compliance for a Harris Stratex Networks' warranty.
- Unless properly protected, a lightning strike can cause equipment failure, or at worst destroy the equipment. It is especially important in regions with high strike incidents to take extra care in the planning and installation of protection measures. Figure 6-6 shows equipment that was damaged by lightning; it is a prime example of what can happen if protection is inadequate.

Figure 6-6. A Strike Damaged IDU

Correct installation of arrestors and cable grounds will mitigate 95% of all lightning strikes. A Harris Stratex Networks site audit program showed that when improperly installed networks were brought into compliance with Harris Stratex Networks Best Practices there was a significant decrease in overall failure rates.

A surge suppressor is not needed for waveguide installations.

Lightning Surge Suppressor Action and Types

The magnetic field generated by a lightning strike on the tower induces a current pulse on all near field conductors, which includes cables fixed to the tower.

With coaxial cables the induced current spike results in a voltage difference between inner and outer conductors, the peak magnitude of which can be thousands of volts. For *low impedance* cable interface circuits, this energy converts to a current which can literally melt components and PCB tracks. For *high impedance* input circuits such as capacity coupled inputs, it is the *voltage peak* which causes component breakdown.

For this reason, a lightning surge suppressor is required to limit the peak voltage difference between inner and outer conductors to a level that will not cause damage to the equipment.

There are two main types of protector, those which are not required to pass dc, such as for an all-indoor radio with a coaxial feeder to the antenna, and those which must pass dc, such as for the IDU/ODU cable in a split-mount radio.

Refer to:

- Non DC Passing Suppressor on page 6-14
- DC Passing Suppressor on page 6-15

CAUTION

Harris Stratex Networks requires correct lightning surge suppressor installation for warranty validation.

Non DC Passing Suppressor

Non-DC passing suppressors are suitable for installation in coax feeders of all-indoor radios. They are not suitable for use within the IDU/ODU cable of a split-mount radio.

Quarter-wave Grounded Stub Type

Most common is a quarter-wave grounded stub type, which behaves as a tuned bandpass filter. Over its narrow pass-band the quarter wave stub offers a high impedance between inner and outer conductors. At all other frequencies it presents a very low impedance, and at dc it presents a short circuit.

One problem with this type is that, if lightning strikes the *antenna*, because the antenna is effectively a tuned circuit, a significant on-tune component of strike energy may be generated, which will be passed directly to the cable interface at the radio. Otherwise, this type of suppressor provides excellent performance and can stand repeated strikes without deterioration in performance.

Ensure the location of an antenna on its support structure is such that it is not at or close to the highest point, and is therefore much less likely to be at the point of strike. Where appropriate a lightning finial may need to be installed at the top of a support structure to provided a well-defined highest point.

DC Blocking Suppressor

A more recent development is the DC blocking suppressor, which provides no dc continuity on the center conductor, pin-to-pin; capacitive coupling is used to provide the required RF continuity. The advantage of this type of suppressor is that by blocking the dc component the let-through energy can be kept to a low level before the associated gas tube reaches its threshold (turn-on) voltage. These types of protector are generally not frequency dependent and will therefore provide protection from dc up to the operational frequency, and above. When selecting this type of suppressor check with the supplier to determine its ability to withstand repeated strikes and its failure mode. The failed mode should be signalled by a hard fault; it should not fail in a way that its inability to provide protection goes unnoticed.

DC Passing Suppressor

A dc passing suppressor is required for split-mount radio installations where a single IDU/ODU coaxial cable is used to carry the IF Tx and Rx traffic signals, IDU/ODU telemetry, and DC power to the ODU.

There are two types of dc passing suppressors:

- Gas Tube
- Matrix

Gas Tube Suppressor

The gas tube suppressor has been deployed extensively with split-mount radio systems. A gas tube shunts the inner and outer conductors, which offers a high impedance except when its threshold voltage is exceeded.

Providing the interface circuits used at each end of the cable have been designed to withstand its relatively high let-through voltage (typically 800 V) at the instant prior to firing, it provides good protection.

However, a gas tube does have a limited strike life and can deteriorate to a point where the tube will no longer fire, or more commonly, it is held on (conducting) by the ODU dc supply voltage on the feeder so that its normally high RF impedance is reduced to a point where it affects traffic integrity on the IDU/ODU cable, with a dribbling BER resulting.

CAUTION

There is no warning provided when a gas tube is faulty, and when dribbling errors occur the suppressor is often the last place to look. For this reason the gas tube capsule in the suppressor should be replaced on a routine basis. Check with the supplier for recommendations on a replacement period.

Harris Stratex Networks has largely changed over from gas to matrix type lightning surge suppressors for split-mount radios.

Matrix Type Suppressors

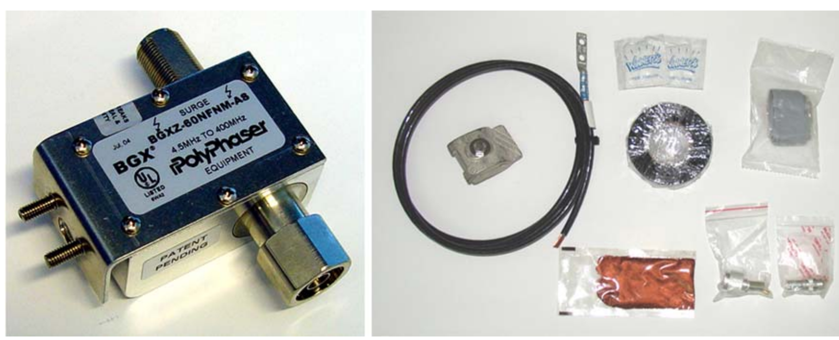
Matrix type suppressors are a recent development and provide a good solution for split-mount radio installations as their design can be tailored to provide a custom let-through voltage.

As an example, for a nominal 48 Vdc (40 to 60 V max 3 A) ODU supply voltage, the maximum operating voltage may be set at 75 V with a peak let-through voltage of 150 Vdc.

Matrix suppressors use a dc-blocked RF path with multiple protection stages in the parallel dc path, which depending on the frequency band and application, may include diodes, metal oxide varistors (MOVs) and gas tubes.

These suppressors can be designed to withstand repeated strikes up to 15 kV and in the event they do fail they should hard-fail.

Figure 6-7. Example matrix type suppressor with installation kit



Suppressor Installation

This section provides:

- Suppressor Installation Guidelines
- Typical Suppressor Installation Procedure

CAUTION

The manufacturer's instructions for lightning surge suppressor installation must be followed. Failure to do so may invalidate warranty conditions.

Suppressor Installation Guidelines

A surge suppressor is normally required at the point of cable entry to the equipment building (just outside or just inside) and is also required at the ODU for split-mount systems. At building entry, the preferred location is just inside the building, or just before the cable enters the building.

- Unless bulkhead mounted to a ground plate, a suppressor should always be separately grounded with its ground wire going directly to the ground bar for a building-entry suppressor, or to the tower steel for an ODU-end suppressor. For building-entry applications refer to Figure 6-8 on page 6-18 and Figure 6-9 on page 6-18.
- When installed just prior to building entry, a separate building-entry cable ground kit must also be fitted, with the suppressor located *between the building and the ground kit*. The suppressor ground should not double as a cable ground. Refer to Figure 6-8 on page 6-18.
- Where the suppressor is exposed to weather it may require full weatherproofing, unless the suppressor manufacturer states otherwise. Regardless, the connectors must be weatherproofed. Weatherproofing materials may or may not be supplied with the suppressor. Refer to the following installation procedure.

Typical Suppressor Installation Procedure

1. Ensure the surge side of the suppressor faces the antenna/ODU and the equipment side faces the indoor radio equipment.
2. Cut the coax cable at the point where the suppressor is to be installed. Terminate the cable each side with the appropriate connectors to mate with the suppressor.
3. If the suppressor is mounted outside, connect the suppressor with the ground wire attachment point/bracket facing downward to help facilitate the shortest route to ground.
4. If the suppressor is not bulkhead mounted, fit the suppressor ground wire, which should be supplied as part of the suppressor kit along with the appropriate nuts, bolts, and washers.
5. Cut the ground wire to length so that there will be just a little slack in the wire when it is connected to its ground point. Do not loop or spiral the wire. If the ground wire is pre-terminated at both ends and is too long, cut the wire to suit and re-terminate with a suitable crimp lug.
6. If the suppressor is fitted outside it may require complete wrapping of the suppressor body and its connectors. Check weatherproofing requirements with the equipment supplier or suppressor manufacturer. Where complete wrapping is required, refer to the procedure outlined in Weatherproofing Connectors on page 4-13 in Chapter 4.

Figure 6-8 shows the suppressor installed outside the building. A separate ground kit is installed just prior to the suppressor.

Figure 6-8. Outside mounted suppressor

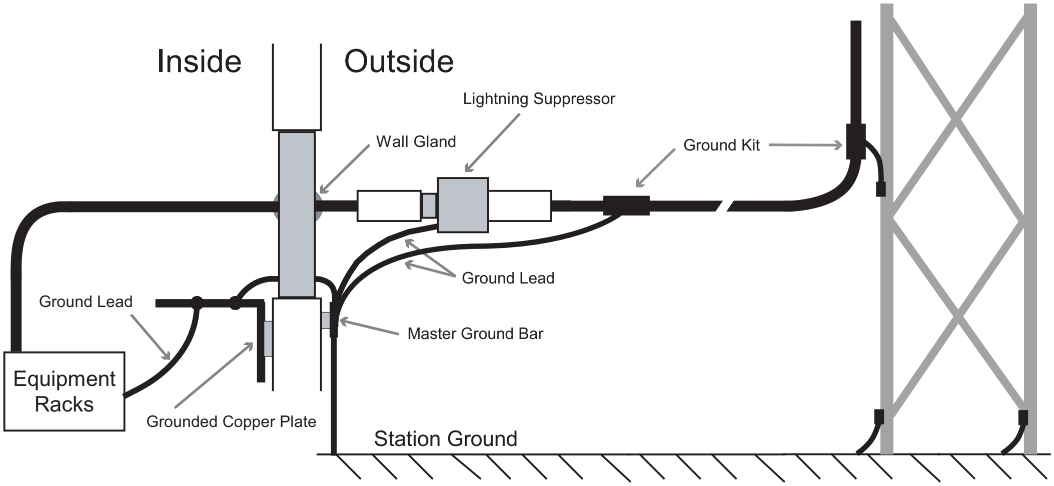
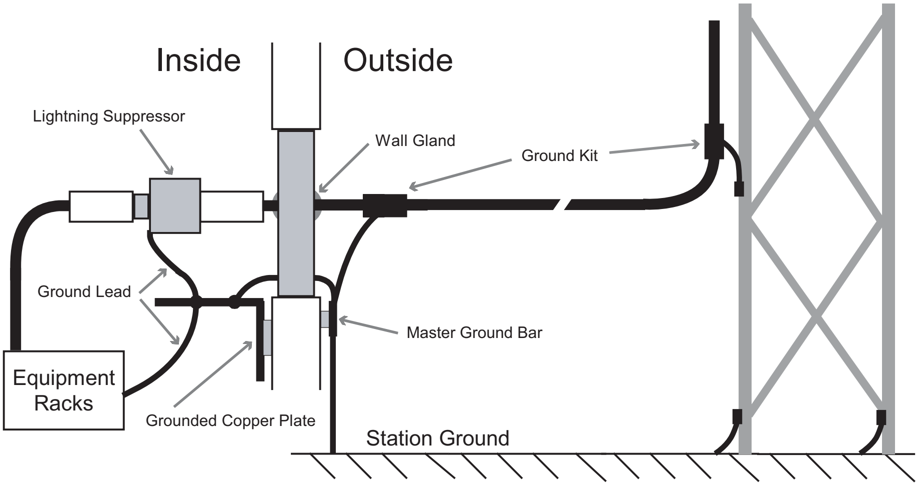


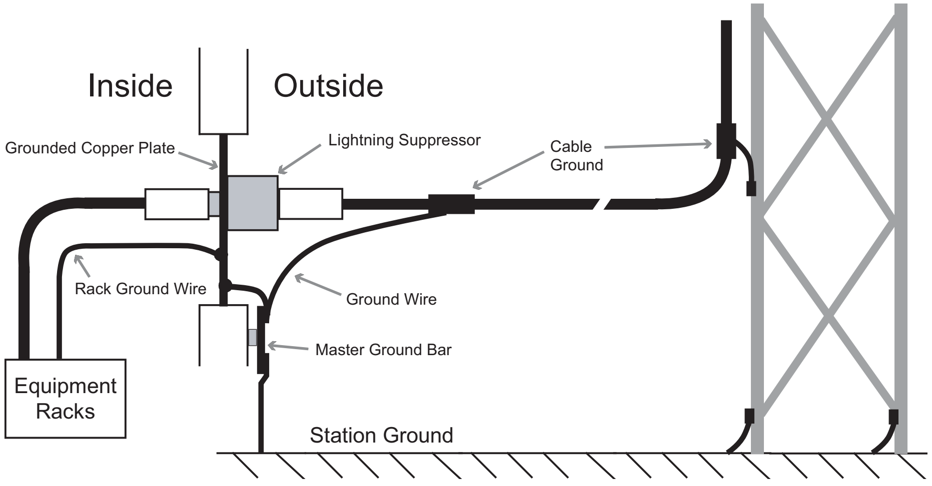
Figure 6-9 shows the suppressor installed indoors, where it should be located close to the building entry point and must be earthed to the master ground bar. A separate cable ground kit must be fitted to the feeder prior to building entry.

Figure 6-9. Inside mounted suppressor



In Figure 6-10 the bulkhead is a copper master-ground-plate. The suppressor body is fastened directly to the plate to provide suppressor grounding.

Figure 6-10. Bulkhead mounted suppressor



Chapter 7. Indoor Equipment Installation

This chapter provides installation guidelines for rack-mounted equipment, specifically the radio of an all-indoor radio and the IDU of a split-mount radio. It includes power supply, grounding, temperature and tributary cable recommendations. Topics include:

Radio equipment and its associated dc power supply must be installed in a restricted access area such as a secure equipment room, closet, or cabinet.

Radio equipment should be installed in the same premises as its dc power supply and be located in the same immediate area (such as adjacent racks or cabinets) as any other equipment that is connected to the same dc power supply.

Rack Installation

CAUTION

A rack must be correctly grounded. For more information refer to Grounding on page 7-4.

Ensure the rack is correctly anchored and top bracing fitted if required.

- If an existing rack is to be used, check to see that the mechanical loading of a new installation does not affect rack stability.

New open-frame or cabinet racks will normally be supplied as kitsets. Follow the manufacture's instructions for correct assembly.

If a new, its location should be noted in the installation datapack.

- Install the rack grounding bar according to the feeder entry point onto the rack; at the top of the rack for feeders supplied from an overhead cable tray, or the bottom of the rack for raised-floor installations. Refer to Rack Grounding on page 6-9.

For cabinet racks:

- If a plinth is required, prepare and install the plinth first.[1]
- Create knock-outs for cable entry (if required) before the rack is fixed into place.
- Check that equipment mounting rails are set at the required distance back from the front of the rack, such that with the door fitted, cables connected to the front of the equipment are not crushed by the door.
- Check that connection of any rear cables is not compromised by the rear door.
- Check that cabinet doors are hung on the side providing best access front and back (left or right hinged).
- Check that any venting options are correctly selected for the intended equipment installation.

1 A plinth may be required to allow cable entry at the bottom of a rack. Or an insulating plinth may be required to isolate a rack from ground at single-point-grounded sites where the concrete floor is in direct ground contact.

Equipment Installation

Equipment must be installed in accordance with the manufacturer's instructions.

This section provides general installation recommendations for:

- Airflow and Temperature Considerations
- Installation Into Rack and Module Handling
- Grounding

Airflow and Temperature Considerations

Determine if the equipment requires special airflow clearances.

Requirements may call for a spacing, such as ½RU, above and below the equipment. If fan cooled, the airflow entry/exit vents must be clear of any obstructions, including cable forms and the like.

Check that cabinet venting is satisfactory. Existing venting may have been adequate for the existing installation, but with additional equipment fitted further venting may be required.

If the internal temperature of the building or the cabinet rack appears to be excessive, measure the temperature to ensure that the ambient temperature limits (Tmra) for the equipment to be installed will not be exceeded. This assessment must take into account the expected extra heat contribution from the equipment to be installed.

If the radio is being installed in an outdoor cabinet, ensure that solar gain during high ambient times of the year will not elevate internal temperatures beyond the equipment Tmra. Solar gain can add 10+ degrees Celsius (18 F).

Installation Into Rack and Module Handling

Carefully check and mark the required equipment mounting height on the rack. Being out by as much as one bolt hole can impact latter installations.

The attachment ears of the radio must have good electrical contact with the rack mounting rails to minimize resistance to ground in the event of a lightning strike. If required, remove paint from the rack rails before installing the equipment. Refer to Grounding on page 7-4 for details.

Radio equipment must also be wired to the rack ground bar. Refer to Grounding on page 7-4 for details.

Take care when installing the equipment into the rack. This should be a two-person job (one to hold, one to fasten) to avoid damaging the equipment being installed, or existing equipment.

When installing modules into a radio refer to Module Handling and ESD Precautions on page 7-4.

Module Handling and ESD Precautions

Where the equipment requires the fitting of modules or an exchange of modules, special care must be taken to avoid damage to cables and components, and to avoid compromising EMC integrity.

- Check the equipment user manual for advice on ESD precautions. Where required, wear proper ESD grounding straps when changing or handling modules. When a module is removed it should be placed in an anti-static bag while you are still connected to the equipment. Similarly, a module should only be removed from its anti-static bag for installation when at the equipment and when connected to the equipment via an ESD grounding strap. Spare modules, or modules to be returned for service, must be enclosed in an anti-static bag.
- With plug-in PCBs, also avoid hand contact with any exposed components. Handle the PCB by its edges or front panel. *This is not an alternative to taking correct ESD precautions.*
- Do not withdraw plug-in modules by their front-panel cables. Use the finger-pulls provided for the job. Similarly, do not withdraw a multi-way connector via its cable; always pull on the connector barrel.
- Keep any removed blanking panels for possible future use. Empty slots may need to be covered with a blanking panel to avoid compromising EMC integrity and any forced-air internal cooling.

Grounding

Equipment installed in racks must be correctly grounded. This means ground bonding between the equipment ears and rack rails, and for the installation of a ground wire from the equipment to the rack ground rail. The rack itself must be grounded to the master ground bar.

Refer to:

- Attachment Bracket Bonding
- IDU and Rack Grounding
- Ground Terminals and Lugs

WARNING

Proper equipment grounding is required to protect on-site personnel against possible electrocution, and to guard against equipment damage in the event of a lightning strike at the site.

Attachment Bracket Bonding

The equipment attachment brackets or “ears” must have good electrical contact with the rack mounting rails. If the rails are painted, best bonding will be achieved by carefully and neatly scraping away the paint where the ears butt against the rails. To make a neat job use tape to mask off the rail where you do not want paint removed. The prime purpose of ensuring a good electrical contact between the radio and the rack is to minimize resistance to ground in the event of a lightning strike.

- A satisfactory alternative is to rely on the grounding provided by the rack fastening screws, *but only* if the rail holes are directly threaded and are clean of any paint, and the rack screws are used without insulating washers under their heads so that there is direct ground bonding via the rack screw between the equipment and the rack rails.

IDU and Rack Grounding

All rack-mount equipment should be fitted with a grounding stud or bolt-hole for ground wire attachment. This may be on the equipment chassis or on one of its attachment brackets.

IDU Grounding - 4 Simple Rules

Follow these four rules when installing ground wires within a rack:

1. Each rack-mounted item of indoor equipment must be separately grounded to the rack ground bar. Do not daisy-chain indoor equipment grounds.
    - Figure 7-1 shows *incorrect* grounding practice.
    - Figure 7-2 shows *correct* grounding practice.
2. The ground leads should be green or green/yellow, PVC insulated copper stranded wire.
3. The ground leads must have a minimum wire size of 4 sq mm/14 AWG.
4. Only use the correct size ground terminals or lugs for the ground-wire size.

Figure 7-1. *Incorrect* IDU Grounding

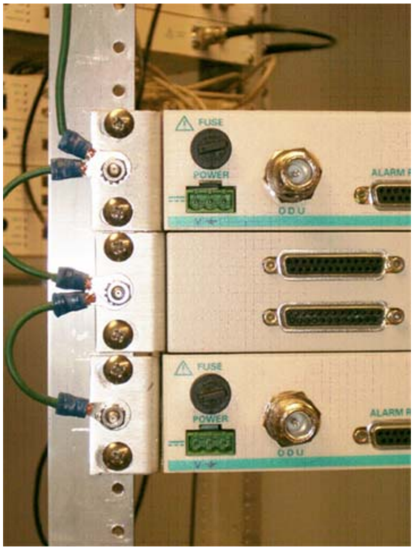
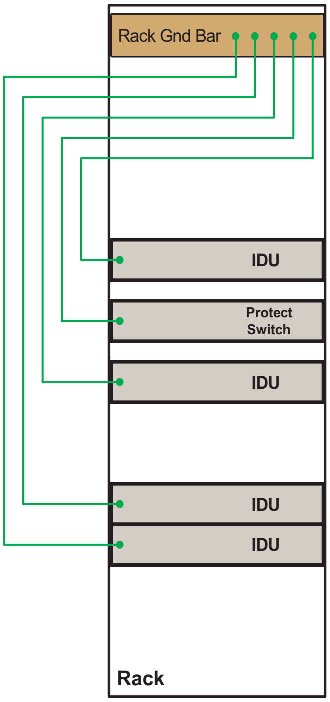


Figure 7-2. *Correct* IDU Grounding



For more specific information on site grounding, refer to *Chapter 6. Lightning Protection and Site Grounding Requirements*.

Rack Grounding

The rack must be properly grounded to the MGB. Refer to Ground System Requirements on page 6-4 for details.

- If the equipment is being installed in an existing rack, do not assume that it is correctly grounded. Always check the integrity of the ground connections, which must include a check through to the MGB.
- Ensure the power supply supplying dc power to the rack is properly grounded to the MGB.
- Measure the ground resistances to the MGB. This is most conveniently achieved with a clamp-on ground tester. All ground wires within the building should have a measured resistance of less than 0.5 ohms.

Ground Terminals and Lugs

The quality of connections made at ground points is fundamental to providing secure grounding; connections must be as direct and as tight as possible.

A lug or terminal in the context of the section is a connector that has a circular hollow shank into which the bared wire is inserted. The shank is crimped using a special crimp tool to provide mechanical fastening and electrical connection. They may be supplied with or without a size-indicating color band around the shank.

Smaller lugs can be crimped using single-action crimpers. Larger lugs will require a compression crimper, where the crimp process is achieved through repeated closing of the crimper handles.

Where crimp lugs (terminals) are used it is essential that the lug size is correct for the wire size, and that the crimp process is performed correctly.

The following rules apply to fitting crimp lugs:

1. Only use the correct lug size for the wire being used. Do not remove strands from a conductor to make it fit.
2. Only use proper crimpers with the right die. Do not use pliers or other such tools.
3. The correct number of crimps must be performed for each lug size; larger lugs require 2 or more crimps. Crimpers are available that will perform multiple crimps in one action, but if single action crimpers are used, then the action must be repeated to complete the correct number of crimps. Table 7-1 shows a chart of the most common ground wire sizes used when installing microwave radio equipment, and the number of crimps typically required on each lug/wire size. Note that for 33 mm^2/AWG 2 wire, 2 or 3 crimps are

generally required; this will vary by manufacturer and is generally shown on the lug body. The chart also shows the normal length of wire that must be stripped for correct fitting into a lug.

Table 7-1. Wire Strip and Crimp Table

Wire Size mm sq	Wire Size AWG	Strip Length mm	Strip Length inches	No. of Crimps
33.6	2	30-32	1-1/4 to 1-3/16	2-3
13.3	6	27-28.5	1-1/16 to 1-1/8	2
4.0 - 6.0	12-10	7	9/32	1
1.5 - 5.0	16-12	7	9/32	1

Lug Installation

Use the following procedure when fitting a crimp lug:

1. Check the lug size is correct for the wire size.
2. Strip the wire to the length specified in Table 7-1. Take care not to nick/cut wire strands in the process.
3. Ensure the exposed center conductors are clean and bright. If necessary surface-clean to remove any oxidation or contaminates.
4. Insert the bared wire into the lug until it stops.
5. Apply the required number crimps. For a color-banded lug they must be applied within the band. Refer to Crimps in Table 7-1.
6. Inspect for any sharp edges or burrs and remove as necessary.

Power Supply Selection and Installation

Most point-to-point radio systems are designed for 48 Vdc operation. The exceptions are radios available with 24 Vdc or 115/230 Vac options. Typically, a radio specified for 48 Vdc operation will have an operating window of 40 to 60 Vdc, and a 24 Vdc radio an operating window of 19 to 32 Vdc. Some radios feature a wide-range capability to allow direct connection to either a 48 Vdc or 24 Vdc supply.

Another selection consideration is connection polarity. Some radios will accept a fully floating supply and allow either side to be grounded (either +ve or -ve). Others will require a +ve or -ve ground, though the PTT/carrier standard of -48 Vdc, +ve ground, is most common.

Most radios for dc operation are Safety Extra Low Voltage (SELV) compliant, where the power supply for the radio must not exceed the 60 Vdc SELV limit. 60 Vdc is considered a safe voltage to touch, however SELV does not place a limit on the current or energy level available, which for a battery backed supply may allow many tens (or even thousands) of amps to be drawn under fault conditions.

WARNING

In such situations the hazards can range from local burns to explosive fire. For this reason battery supplies in particular must be current limited or fused.

The battery bank must be installed according to manufacturers instructions and be protected such that tools or other electrically conducting objects cannot fall across bare battery terminals.

A further SELV requirement is that the secondary circuit (supply side) of the power supply must have no direct connection with the primary power source, the 115/230 Vac mains input. The secondary circuit must derive its power from a transformer, converter or equivalent isolation device, or from a battery.

For supply selection and installation topics refer to:

- DC Power Supply Types and Reliability Considerations on page 7-10
- Power Supply Installation and DC Connection on page 7-12

For SELV regulatory details, refer to IEC publication EN 60950.

Most countries require type and safety certification of the power supply, such as compliance with IEC or UL standards. Check local regulations for exact requirements.

DC Power Supply Types and Reliability Considerations

The type of power supply needed will depend primarily on the load and reliability requirements. While load capacity is self evident, reliability[2] (dc supply continuity) considerations include N+1 redundancy, load sharing, hot plug-in, and battery backup.

Power systems are available for low capacity, single radio installations, through to systems for high demand telecommunications centers. Small capacity systems are available for rack mounting.

Guidance is provided on:

- N+1 Redundancy on page 7-10
- Load Sharing on page 7-10
- Hot Plug In on page 7-11
- Battery Back-Up on page 7-11
- Transportation Considerations on page 7-11

N+1 Redundancy

Most telecommunications power supply systems are constructed on a modular basis where multiple (N) rectifiers operate in parallel to deliver the required load. In so doing an amount of over-capacity is designed in to ensure continuous DC supply in the event of a rectifier failure. If a system requires N rectifiers, then one additional rectifier (+1) is added in backup such that no single rectifier failure will jeopardize the integrity of the supply; if any one rectifier fails then there will always be sufficient rectifiers to maintain the full load.

Load Sharing

Load sharing ensures that the total system load is actively shared between all rectifiers. It improves reliability by ensuring all rectifiers are equally stressed for load and temperature (the lower the stress the better the long term reliability). Without load sharing, some rectifiers could be operating at 100 per cent capacity, while others could be at idle.

For an N+1 system the +1 rectifier is included in the load sharing, which also improves power transfer from a failed rectifier as the magnitude of the current transient seen by the remaining rectifiers is lower.

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[2] Primary reliability is directly related to the MTBF of the rectifier or rectifier modules. N+1 redundancy and hot plug-in are only required when a rectifier has failed.

Hot Plug In

Hot plug in (hot swap) permits the replacement of a failed rectifier without shutting down the dc system. It is achieved by soft starting the rectifier and using protection diodes to ensure the uncharged capacitors on the replacement rectifier don’t cause a spike on the dc power bus.

Battery Back-Up

Battery back-up uses storage batteries (maintained on charge by the rectifiers) so that in the event of an ac mains failure (or multiple rectifier failures), the batteries provide the power to the load until restoration. Batteries also have the added advantage of virtually eliminating transients on the dc output.

The batteries represent an additional load which must be included in the system load specification. The size of the additional load will be proportional to the battery capacity and the required battery recovery time after discharge.

Load current and battery operating time are the two principal dimensions in calculating required battery capacity. Battery size and cost is directly proportional to capacity.

Sealed lead acid storage batteries are generally used, and are available in a range of capacities and qualities. Other battery types in use include wet lead acid, and sealed and wet nickel-cadmium (Ni-Cad). Ni-Cad batteries have particular application where extreme life and/or operation over extreme temperature ranges are needed.

Specialist suppliers of power systems will be able to provide recommended battery solutions for a particular application.

Transportation Considerations

Power supplies and storage batteries are large, heavy and expensive objects to transport. When selecting a power system, consideration should be given to the source and the method of transportation. A local/regional or in-country supplier may provide substantial cost savings on a delivered system. If appropriate, consider sourcing the power supply and back-up batteries separately, with special emphasis on local supply of suitable batteries.

If airfreight is essential, sealed batteries are the only choice. Wet batteries, unless empty of electrolyte, will not be accepted for airfreight without special conditions.

Power Supply Installation and DC Connection

This section provides information on:

- Power Supply Installation Guidelines on page 7-12
- DC Connection on page 7-12

Power supply systems must be installed in accordance with manufacturer's instructions.

Power Supply Installation Guidelines

General guidelines for power supply installation include:

- Check local regulations on locating the power supply. Some countries require the power supply to be located within the same equipment room as the equipment it is supplying, with special emphasis on common grounding.
- At sites where lightning surges on the ac mains supply are a concern, consult with the power system supplier to determine if additional primary or secondary surge suppression is recommended or required.
- The power supply and any battery backup must be firmly anchored/secured. While power supplies will have anchor/mounting points, most storage batteries do not. In territories where earthquakes are possible, secure restraint is essential.

DC Connection

Consideration must be given to the installation of the dc supply wiring, and to the load protection required for each circuit. For small systems supplying just one radio, circuit protection built into the power supply may be adequate. For large installations, separate and correctly load-sized circuit protection (circuit breakers) should be installed for each rack and for each item of equipment supplied within the rack.

- Where the power supply has one leg grounded, there must be **no** disconnection device (switch, circuit breaker, or similar) installed in the grounded wire.
- If the power supply is floating above ground (+ve and -ve isolated from ground) circuit protection can be installed in one leg/pole of the power feed. *Ensure that all downstream protection devices are installed on the same leg/polarity*.
- For a new power supply installation, check that it has been properly inspected and commissioned before a radio or other equipment is connected to it.
- Follow instructions from the radio manufacturer for the correct size of wire to use when wiring to a power supply.

- If an existing dc power supply is to be used, check that its dc supply wiring, protection devices and any battery back-up have adequate capacity for the new loading.

CAUTION

Before connecting equipment to a power supply, double check supply voltage, polarity and dc grounding.

Never assume that an existing power supply installation is OK to connect to. Always check the integrity of its supply wiring and ground wiring.

Radio Switch On

Before powering up a radio for the first time, check the following:

1. Power supply voltage and polarity are correct at the power input connector to the radio.
2. Radio fuses and circuit protection devices in the dc supply line are rated correctly.
3. All grounding for the radio, rack, feeder/ODU cable is correct and complete.
4. All required lightning surge suppressors are correctly installed.
5. Any waveguide or air-dielectric coax feeders are correctly installed and are serviced by an operating dehydrator.
6. The antenna has been correctly pre-aligned, which may be to visual or compass references.
7. Where the equipment is supported by a PC based craft tool, ready the PC and its connection to the radio.
8. Prepare to check radio Tx and Rx frequencies, and Tx power. Before switch-on it may not be possible to verify existing/default settings, and if the Tx cannot be muted before switch-on, be prepared to check and change frequencies and Tx power immediately after switch-on. If the radio is on the wrong frequency and/or Tx power setting, interference to other links in the same geographical area may occur.

With power switched on and correct frequency and power settings confirmed, check initial operation by observing the front panel status and alarm indications, followed by craft tool performance indicators.

If all indications are OK, proceed to the antenna alignment and commissioning checks.

Tributary Cabling

Coaxial and optical tributary cables are normally supplied pre-terminated. Ensure the correct type, length and quantity have been supplied for the installation.

Refer to:

- Tributary Cable Installation Guidelines on page 7-14
- Handling Fiber-Optic Cables on page 7-14

Tributary Cable Installation Guidelines

Where cables are to be made up, ensure the correct cable and connector types are at hand, plus instructions on how to prepare the cable and fit the connector. This will normally only apply to coax and balanced wire trib cables; optical trib cables are almost always supplied as finished assemblies.

When installing trib cables take care to ensure their location does not impair access to plug-in modules or hide alarm indicators such as LEDs.

Where the radio is installed in a cabinet rack, ensure trib cables are not crushed by the closing of the cabinet door. In some instances, it may be necessary to set the radio equipment back from the rack rails using rack ears designed for the purpose, or by other means.

Trib cables should be neatly secured within the rack and have identification tabs or rings attached at each end to identify their connect-to and connect-from points. A convenient device for preparing labels is a hand-held, battery-powered, label printer using thin adhesive-backed label strip. The strip can be neatly wrapped around the cable to form a ‘flag’.

Handling Fiber-Optic Cables

Fiber-optic cables require special attention when handling:

- When removing the fiber-optic cables from their package, avoid any action that may cause the fibers to bend or coil excessively. Glass fibers are fragile and can break.
- Avoid using tie wraps to secure fiber cables. If pulled tight, excessive local pressure may cause fibers to break.
- Avoid bending fiber cable too sharply. The minimum bending radius is typically 10 times the diameter of the cable. For single patch optic cable, the minimum bending radius is 50mm (2”).
- Always cap the ends of unused optical connectors. Dirty or dusty optical cable ends can cause bit errors.

- As with conventional connectors, wear on fiber connectors can induce power loss, which may eventually cause errors. Connectors are rated by cycles: one connect/disconnect is one cycle. Ceramic optical connectors are rated at around 500 cycles, metal connectors at around 100 cycles. Whenever possible, avoid repeated cycles to extend the life of the connector.
- Before connecting fiber-optic cables, check optical level settings at both ends, radio and multiplexer, to ensure compatibility. An under or overdriven optical receiver will cause bit errors. If necessary use a fiber-optic power meter to measure levels.

WARNING

Always properly dispose of broken or damaged fiber. Small particles of broken fiber (glass) can irritate, or cause serious damage to skin and eyes.

WARNING

Never look into the end of a fiber-optic cable which has the other end connected to equipment. The energy wavelengths used are outside of the visible spectrum so even when active, a fiber cable *appears* inactive. *Always assume that laser energy is being emitted*.

CAUTION

Avoid using nylon cable ties to secure optical cables. Most have a soft plastic sheath, which is easily deformed and when ties are tightened.

Chapter 8. Commissioning

Commissioning is about ensuring that the installed link:

- Is installed correctly
- Is correctly configured
- Has passed all tests
- Is operating to plan and running alarm and error-free
- Has had all relevant commissioning data recorded
- Is ready for traffic carrying duty

A commissioning check procedure should be supplied by the radio link manufacturer, which in some instances may be supplemented by additional procedures from the customer/operator.

These procedures may include or have as a separate document, a site inspection check-list, which specifically addresses the physical installation such as grounding, weatherproofing, and feeder/cable fastening and labelling.

A further document frequently used is a site/link completion and hand-over form, which formally acknowledges work completion by an installer. It may also set out any remedial work required, whose responsibility it is to do the work, and when the work should be completed by.

Example commissioning forms are available from HSX as editable Excel formsets. Refer to Installation and Commissioning Formset, Appendix B.

Commissioning Tests

This section provides guidance on typical path and equipment tests for commissioning. Where provided, radio link manufacturer's instructions for these tests must take precedence.

Fade Margin

This test is designed to check that the expected (calculated) fade margin for a link matches actual performance. The expected fade margin should be included in the link datapack together with Tx power, system losses, antenna gains, the effective radiated power, free space path loss, expected receive signal level and the calculation for link availability.

The fade margin test measures the difference in receive signal level between the normal, operational level, and the threshold level, the level at which bit errors appear. The threshold level can be specified for a bit error rate (BER) of 10^{-6} or 10^{-3}.

This fade margin measurement should only be conducted after it has been verified that the expected receive signal level (RSL) for normal link operation is present at both ends of the link.

> If the receive level is low, the reason must be investigated and resolved before conducting a fade margin test.

If both RSLs are low, reasons can include:

- Path loss higher than expected, which may be due to an incorrect path survey or profile calculation, or localized fade conditions, such as rain fade or ducting
- Antenna misalignment
- Higher than expected losses one or both antenna feeders
- Equipment performance outside specification

If just one RSL is low, reasons can include:

- Low Tx power from the remote end
- Poor Rx performance at the local end

If RSLs are normal and the measured fade margin is significantly lower than expected, reasons can include:

- Equipment performance outside specification
- Interference from other transmitters

The accuracy of the measurement will depend on the method and the accuracy of the measurement devices. For maximum accuracy a calibrated variable attenuator or multiple fixed attenuators should be inserted in the feeder. However, for waveguide and heavy coax feeders the specialized attenuator(s) and flange/connector interfaces needed, coupled with the difficulty of insertion for test purposes, make for a difficult process. For split-mount installations it is just not possible. Craft tool (software) adjustment of Tx power is a much more practical method, though with some radios there may be insufficient adjustment range. Also remember that the Tx power setting (or Tx forward power indication) from a radio will certainly not be as accurate as the adjustment provided by a calibrated external attenuator.

Refer to manufacturer’s specifications to assess the accuracy of Tx power setting and any built-in power measurement capability.

Fade Margin Measurement Procedure

The following fade margin measurement procedure is based on varying the Tx power by software command. However, the same procedure can also be broadly applied to power adjustment using an external attenuator.

For information on fade margin computation and loopback setting, refer to Diagnostic Tools on page 9-7.

1. Note the Tx power setting, or preferably the forward power reading if provided. Note the RSL at the other end of the link.
2. Prepare to monitor BER alarm thresholds at the receive end.

Use an external BER tester on a looped tributary if an internal BER test and measurement capability is not provided.

3. Reduce the Tx power in steps until the receiver 10^{-3} or 10^{-6} threshold is just reached as indicated by the BER alarm or performance monitor.

For modern digital microwave links, the difference between 10^{-3} and 10^{-6} thresholds will usually only be about 2dB.

4. Calculate the fade margin by working out the difference in Tx power between normal power and the threshold power setting.
5. At the thresholds, the indicated receiver RSLs in dBm can also be compared with the receiver datasheet specifications as a direct check of receiver 10^{-6} and 10^{-3} BER thresholds.

The margin for error using this method will typically be between 3 dB and 4 dB, bearing in mind the limitations of software-set power control and BER measurement within commercial grade radio links.

For a receive threshold check, the margin for error may also be up to 4 dB given the limitations of *internal* RSL and BER alarm measurement.

Measurement accuracy may be improved with the use of an *external* BER tester.

BER Test

A BER test is used to check that a link is passing traffic error free for the test period (normally a minimum of 8 to 12 hours (overnight)).

It is normally conducted at trib-level, though if the radios have a G.826 background error measurement capability, it can also be conducted at a radio-radio level.

Strictly speaking a BER measurement should be conducted using a G.821 test. When conducted using G.826 parameters, the data presented is based on errored blocks and errored seconds, not as bit errors as for G.821, although an estimated BER can be provided from the base G.826 data.

Where the measurement is conducted in conjunction with a loopback refer to Diagnostic Tools on page 9-7 for loopback information.

The test can be conducted using a built-in test capability where provided, or by using an external BER tester on a selected tributary:

Built-in BER Test

Built-in test capabilities normally fall into two categories, one which provides continuous background performance measurement, and one which is user selected to provide a BER test on a tributary (normally activated in conjunction with loopback controls).

Depending on the capabilities of the built-in test and the requirements of the customer/operator, either the background measurement or the tributary test (or both) may be acceptable for commissioning purposes.

Background Performance Test

Background measurement for a radio link is usually G.826 based with the source data provided from the FEC circuit, specifically from a count of uncorrectable blocks. It is single link based, originating in the modulator at the Tx end, and extracted from the demodulator at the Rx end. As such, the check does not incorporate the mux/demux or tributary circuits. However, because it is operating continuously in the background the data collected can be used to provide a performance history over days and weeks. Traffic is not affected.

With some radios this G.826 data may be supplemented with an estimate of

G.821-based background BER.

BER Tributary Test

A BER tributary test is usually G.821 based and uses a BER generator (pseudo-random test pattern generator) to provide a test signal onto a user selected tributary, such that with a loopback activated the test signal is returned to the source where it is directly compared with the sent signal. Or with some equipment the test signal can originate within one radio and be checked at another for a one-way test. Unlike the background measurement, it can be used to check a tributary circuit beyond the remote end of a link, meaning multiple links can be involved. Such multi-hop tests are usually established from a network management system. Traffic is affected; existing traffic on the selected tributary is replaced by the test.

External BER Test Set

External testers provide a wider range of test and measurement functions than built-in testers. Versions are available for testing on-line rates from fractional E1/ DS1 PDH through to SDH/SONET.

These are transmit/receive devices, which provide a selection of transmit test patterns and sequences. It is normally used in loopback mode where the received signal is compared to the transmitted pattern for error performance.

The receiver can also be used on its own to monitor an in-service tributary by bridging across it to check parameters such as line levels, clock frequency, frame alarms, presence of AIS, pulse shape, and CRC-4 error checking in response to the error correction activity generated by the equipment being monitored.

Where customers/operators require measurement of parameters not typically provided on built-in testers, the external test set is the only option.

ITU Error Performance Recommendations

The two ITU error performance recommendations most referred to within the industry are G.826 and G.821. G.826 has largely replaced G.821, except for sub-rate connections (less than 2048 bps / E1).

Other ITU error performance recommendations include G.828 and G.829, which are designed to better match the capabilities of SDH systems.

G.821

G.821 error performance is based on 64 kbps connections. For connections operating at a higher rate, the results obtained are normalized to a 64 kbps channel.

However for rates in excess of 2 Mbps this normalizing process is considered flawed, and it was primarily because of this, and an industry requirement for *in-service* testing, that G.826 was formulated.

G.821 based measurement remains in wide use for error measurement at E1/DS1 and fractional rates.

G.821 error performance parameters are based on measurement of errored bits, giving rise to measurement of a bit error ratio. However, errored bits can only be clearly recognized if the bit sequence being monitored is known, which means the circuit to be measured must be taken out of service while the test pattern is applied.

G.826

G.826 was designed for error performance measurement on circuits with bit rates higher than E1/DS1 (higher than 2 / 1.5 Mbps), and to allow in-service measurement. It is non-transmission-medium (radio, fiber, wire, and so on) dependent, and non-system dependent, meaning it supports measurement on PDH, SDH and cell-based systems. Its performance objectives are also higher than G.821 and requires detection of errors with at least 90% probability.

The move to in-service performance assessment was to allow for use of built-in error monitoring equipment, which required a move away from bit error measurement towards block error measurement.

Block monitoring takes advantage of the FEC (forward error correction) monitoring and correction circuits built into modern transmission equipment. Typically the block size equates to the FEC frame size, which is specified by the number of bits or bytes per frame. (Block size = FEC frame size)

At this point it is as well to note that under G.826 recommendations the performance objectives are for a hypothetical 27,500 km reference path with the total circuit split into national and international portions and the block size sized separately for different system rates. Block sizes typically vary between 800 and 5,000 bits per block for bit rates from 1.5 to 5 MHz, and between 4,000 and 20,000 bits per block for bit rates from 55 to 160 MHz. This is in sharp contrast with the G.826 interpretation for a typical microwave link, where the performance objectives apply to a single hop, and for links supporting software selection of different data rates the block size is similar for all rates.

The reason for the similar block size in a multiple-rate radio is that the FEC circuit operation is common to all rates. A typical modern microwave link for PDH and SDH capacities will have a block size of 1600 to 2000 bits (200 to 250

bytes).

G.826 Monitoring and Measurement

Table 8-1 shows the four error events that G.826 monitors.

Table 8-1. G.826 Monitoring

Event	Description
Errored Block (EB)	A block in which one or more bits are in error.
Errored Second (ES)	A one-second period with one or more errored blocks or at least one defect.
Severely Errored Second (SES)	A one-second period which contains at least 30% errored blocks or at least one defect.
Background Block Error (BBE)	An errored block not occurring as part of an SES.

Measurement of these events requires absolute counts. For practical reasons the preference is to use ratios. Refer to Table 8-2.

Table 8-2. G.826 Measurements

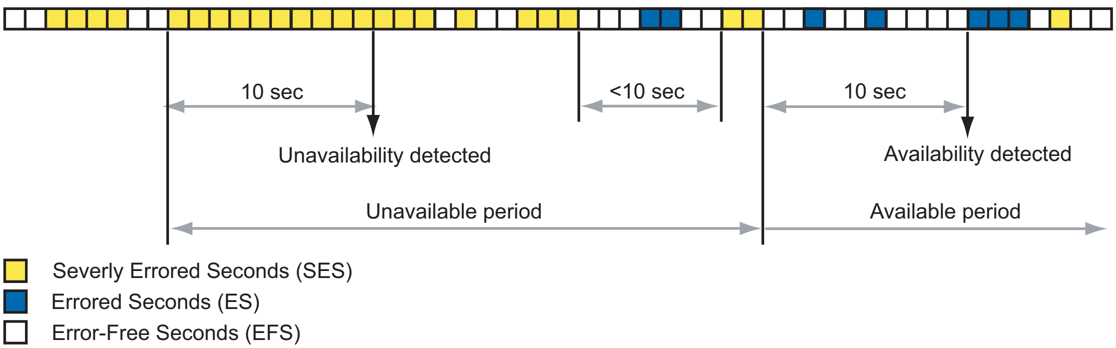
Measurement	Description
Errored Second Ratio (ESR)	The ratio of ES to total seconds in available time during a fixed measurement interval.
Severely Errored Second Ratio (SESR)	The ratio of SES to total seconds in available time during a fixed measurement interval.
Background Block Error Ratio (BBER)	The ratio of Background Block Errors (BBE) to total blocks in available time during a fixed measurement interval.

In accordance with the definition of error events, blocks occurring within severely errored seconds are not considered when computing the Background Block Error Ratio (BBER).

For all three *ratio* definitions, only the time during which the transmission system is available is considered when forming the ratios

For the purposes of Recommendation G.826, availability ends at the start of a time interval containing at least ten consecutive severely errored seconds in at least one direction of transmission. The system becomes available again at the start of a time interval consisting of at least ten seconds that are not severely errored. Figure 8-1 shows an example of how availability is determined.

Figure 8-1. Example of Unavailability Determination



G.826 data has a 10 second availability latency.

G.828 and G.829

While G.828 has essentially the same structure as G.826 in that it is a block based system, it specifies tighter error performance objectives for SDH operation. It introduced a new error parameter, the Severely Errored Period (SEP), which is defined as a period during which at least three but not more than nine consecutive severely errored seconds (SES) occur. The measurement parameter associated with this is the Severely Errored Period Intensity (SEPI). G.828 also defines tighter values for error performance, specifically ESR and BBER.

G.829 builds on G.828 to provide recommendations on error performance events for SDH multiplex and regenerator sections.

Comparing G.821, G.826, and G.828 Error Performance

A direct comparison between G.821 and G.826/G.828 is not possible due to the differences in defining the error events. G.821 is bit error oriented, whereas the others are block based. To enable a comparison requires knowledge of how the bit error ratio relates to the errored block, specifically error distribution versus time. For example, if errors occur in a burst, G.821 would count a number of bit errors, while G.826/G.828 might count only one errored block. If the errors are equally distributed vs. time, then each bit error can produce a block error. It can be verified however, that depending on the error model, the requirements of G.826 and G.828 can be much tougher than G.821.

Protection Switching

Testing protection switching is about confirming that a protected, diversity, or ring link operates in accordance with its protection switch settings in the presence of an equipment fault or path error. The manufacturer’s equipment user manual should specify the switch criteria, and a procedure to check for correct operation. Table 8-3 describes the types of checks to be performed on each link type.

Table 8-3. Protection Switching Checks

Link Type	Checks
Hot Standby Link	• Correct switching from/to all A side, B side (main - standby) combinations. • Hitless Rx switching is hitless. • Tx switching restores correct link/traffic operation within the specified period. • No switching is attempted to a standby Tx or Rx if it is in alarm. • That where a protected system has a preferred side *and* an automatic return to the preferred side, that the preferred side is restored automatically when a fault on the preferred side is cleared. This must be checked for the preferred Tx and Rx separately. • The appropriate front panel and management alarms are indicated for the various states.
Space Diversity Link	• Rx selection is hitless. • Tx switching restores correct link/traffic operation within the specified period. • That no Tx switching is attempted to the standby Tx if it is in alarm. • The appropriate front panel and management alarms are indicated for the various states.
Frequency Diversity Link	• Rx and Tx selection is hitless. Putting any Rx or Tx into alarm does not cause a traffic error. • The appropriate front panel and management alarms are indicated for the various states.

Link Type	Checks
Ring	• Correct operation of ring circuit switching or ring wrapping for a protection event. • Correct auto-restoration of the ring on clearance of the event causing the switch. • That ring traffic is restored within specified periods when the ring is initially switched and when restored. • The appropriate front panel and management alarms are indicated for the various states.

Network Management Visibility

Ensure the configurations and connections for network management visibility are correct by checking:

- That the operations center has visibility of both ends of the link for read/write action where the link is under full network management.
- That there are no on-screen warnings or other indicators which may suggest incompatibility of software versions from a management perspective.
- Where only summary alarms are presented to the management center, ensure that management center interpretation agrees with the indicated alarm conditions at the terminal.

Accessories

- Check for correct configuration and operation of installed accessories such as Engineering Order Wire (EOW), or a data accessory option.

Where EOW is enabled on an Ethernet connection using a VoIP phone, interoperability throughout the network will require complete and correct IP addressing for all radios/sites. This may differ to the IP addressing requirements for the NMS, as the operations center only needs visibility to the radios, and not between radios.

- Check that expected front panel and network management alarm indications for any accessories occur when an alarm condition is simulated.

Chapter 9. Troubleshooting

This chapter provides guidelines on troubleshooting point-to-point digital microwave radio links. The guidelines should be read in conjunction with any instructions provided by the equipment manufacturer and instructions provided with the network management system (where installed).

The following topics are covered:

- Preventative Maintenance on page 9-1
- Fixing Faults on page 9-4
- Diagnostic Tools on page 9-7
- Fault Reports on page 9-18

Preventative Maintenance

This section covers inspection and analysis options, which may help to catch a problem before it brings down a network. Topics addressed are:

- Routine Inspections
- Trend Analysis
- Fault Analysis
- Training
- Spares

Routine Inspections

All sites must be inspected annually, or more frequently if subject to abnormal operating conditions such particularly exposed sites, or sites subject to salt-spray or heavy snow/ice loading over winter months.

The inspection should cover the physical installation including the antenna, antenna feeder or IDU/ODU cable, cable grounding, equipment grounding, tower and building grounds, weatherproofing, lightning surge suppressors where fitted, and general site integrity.

Selected ground wires should be resistance checked and then compared with previous checks to ensure there has been no significant change.

The operational performance of the radio and associated equipment should be checked against their as-built figures using the available front panel and craft tool status, alarm and performance indicators, especially so if the equipment is not managed by an NMS (Network Management System).

Trend Analysis

Use available data to determine any trend that may lead to a failure if allowed to continue. The data for such analysis is most readily provided by an NMS, which can capture and present data on an historical basis. But data captured during a routine inspection may also provide a valuable trend insights.

Check for the following trends:

- Reducing receive signal level
- Gradually increasing bit errors or an increasing errored seconds count
- Changes in transmit power
- Increased frequency of rain fade or other fade conditions
- Increasing occurrence of other weather related changes in performance
- Increasing occurrence of a particular hardware failure

Time spent in conducting such analysis is time well spent. Catching a problem before it brings down the network is good network management.

Fault Analysis

All faults, once cleared, should be the subject of a fault report. The data presented in these reports should be analyzed from time to time to check for any common threads, which may point to a particular weakness in the design, installation, or maintenance of the network or to a specific component or equipment type. Refer to Fault Reports on page 9-18.

The time taken to restore service and the parts used should also be analyzed to see if improvements are possible in the maintenance procedures, maintenance training and spares holdings.

Training

Properly trained and experienced *planning and installation* personnel are essential for establishing high integrity in a new network. Similarly, properly trained *network management and service personnel* are essential for the continued good health of a network.

Training procedures and courses should be reviewed from time to time to check their relevance and cost-effectiveness. Similarly, the training needs for personnel should be reviewed to ensure they maintain expertise in their area of work, and of the installed base.

Spares

Spares holdings should be reviewed on a regular basis to ensure the correct quantity and type are held, and held at the most appropriate locations.

Analysis of spares usage will show any trend for excessive use of spares, which may point to a weakness in the deployment or design/manufacture of the item.

Spares holdings should also be checked from time to time and if necessary brought up to the current hardware and/or software revision level.

Fixing Faults

This section introduces:

- Which Link, Which Site, Which Terminal
- Before Going to Site
- On-Site Checks
- Typical Fault Scenarios

Which Link, Which Site, Which Terminal

A well featured network management system will enable fault location down to a module level for hardware alarms. To separate out essential data, a knowledgeable operator is required to quickly target the likely fault location and cause.

Only where it is not possible to see a network beyond a full break, and therefore not possible to see the far end of a link, does it become less certain as to which site carries the faulty equipment, or if it is an equipment fault as distinct from a full path fade. However, by looking at the events alarm log it should be possible to narrow down the options.

Where the network or link is only supervised by summary alarm reporting, or no reporting at all, then fault identification and location will often require a visit to a site or sites to understand what and where the problem is.

> An NMS saves time and money. Network up-time will be higher and servicing costs and MTTR will be lower than for part supervised or unsupervised networks.

Before Going to Site

Before you go to site, check the following:

- Is it a fault which requires immediate attention, or can it wait till the morning, or until you have completed your present job.
- Confirm the nature of the reported fault, its location, the type of equipment, its frequency band, capacity, modulation and configuration (non-protected, protected, diversity) by asking:
  - Is just one link affected or a number of links in the same geographical area?
  - Is the path down completely or is only one or a number of tributaries affected?
  - Is the path down completely or is traffic passing but with a BER alarm?

  - Is it a hard fault, or is it intermittent in nature?
- Do the alarms indicate which end of the link is faulty? Hardware, software or tributary alarms from an element management system should provide confirmation of the link-end.
- Check the weather conditions leading up to the occurrence of the fault. Could the weather (rain, ice, high wind, temperature, and so on) be a factor in the reported fault.
- If the fault suggests a rain fade or other weather related fade condition and it matches the prevailing weather conditions, do not take any action until the weather abates.
- Check to determine if you or another engineer is best placed to attend to the reported fault. This may be assessed by location, experience, access to spares, and so on.
- Check to see if the alarms suggest the fault may be with connected equipment and not the reported equipment, such as a mux, other radio equipment, or tributary line connections.
- Check the terminal / link history:
  - Is it a newly installed link?
  - Does the fault history for the link indicate a likely cause?
  - Has there been work done on the link in recent times, and if so, what?
- Check that you have with you:
  - The appropriate spares.
  - The craft tool, the right the software revision to enable the craft tool to communicate with the equipment, and a connecting cable for craft tool access.
  - Any password and/or IP address required to secure craft tool access to the equipment.
  - Any special test equipment that may be needed.
  - Toolkit.
  - Key(s) for access to the site, and if necessary, the directions on how to get there.

Where link alarms and performance monitors do not confirm the source of a fault condition, such as a dribbling BER reported at some point in the network, always check the alarms of the connected equipment. Never jump to a conclusion that a radio link is the problem.

On-Site Checks

When first on site check the following before proceeding with a more detailed examination.

- Inspect the terminal status and alarm LEDs. Or if provided, its front panel LCD indications. Check to see if the indications match with the reported fault.
- Log on to the terminal with the craft tool for a more detailed analysis of terminal/link status and alarms. If the terminal holds a message page for user entry of service notes, check to see if any fault-relevant notes exist.
- Subsequent action must be guided by the nature of the fault.

Order of Investigation

Where there are a multitude of alarms, as may occur in many fault situations, always begin with the basics. For instance, do not start to replace equipment or modules without first checking why there is a supply voltage alarm, or investigate a receiver if the far end transmitter is in alarm.

Table 9-1. Suggested Order of Alarm Investigation

Step	Alarm Type	Description
1	Supply voltage alarm	Check that the power supply voltage is within the required range for the equipment.
2	Hardware alarms	Check specific hardware alarms, which may point to a component failure. If a tributary fault is indicated, check the related cables and connectors, and the alarm status of the connected equipment.
3	Software alarms	Check for software corruption and terminal configuration alarms.
4	Performance/path alarms	Check Tx power, Rx signal level, and G.826 path performance data.
5	Outside installation	Inspect the feeder or IDU/ODU cable, connectors, lightning surge suppressor(s), and antenna.

Indirectly Detected and Undetected Faults

This refers to faults that go undetected by equipment alarm monitors or faults indicated by a module that is not the source of the fault. Clearance requires a process of elimination based on experience, knowledge of the equipment, and sound troubleshooting logic.

For example, a noisy receiver local oscillator may cause a high BER condition and possibly a demux alarm. The first approach may be to replace the demux module, but it would not be until the RF module was replaced that the problem would be resolved.

Similarly, incompatible optical signal levels into or out of a link may cause a dribbling BER, which on first analysis may indicate a fault within the radio.

Isolation of this type of problem is assisted by careful observation of alarm indications and historical data.

Typical Fault Scenarios

For fault descriptions, probably causes, and recommended actions for a range of typical path related faults, refer to Appendix D.

Diagnostic Tools

This section describes the following diagnostic tools and processes:

- Loopbacks
- Fade Margin
- Tx Power Measurement
- Feeder Return Loss
- Interference Measurement
- Bench Testing

Loopbacks

Loopback tests are useful in helping to determine the location of a system malfunction, especially if link alarm and performance data provide no clear indication of fault location. Loopbacks are used in conjunction with a BER test-set or built-in BER test capability to determine the points within a link at which normal (un-errored) operation ceases and errored operation begins, with the section between normal and errored operation denoting where the fault lies.

Some radios have a built-in pseudo-random BER generator and receiver. For radios not fitted with this feature, an external BER test-set is required.

Most radios provide capabilities to apply a loopback at the tributary, baseband (digital), IF and RF stages. Figure 9-1 shows typical loopback points for a split-mount link. Table 9-2 on page 9-9 provides a brief explanation of each loopback.

Figure 9-1. Example Loopback Settings with an External BER Test-Set

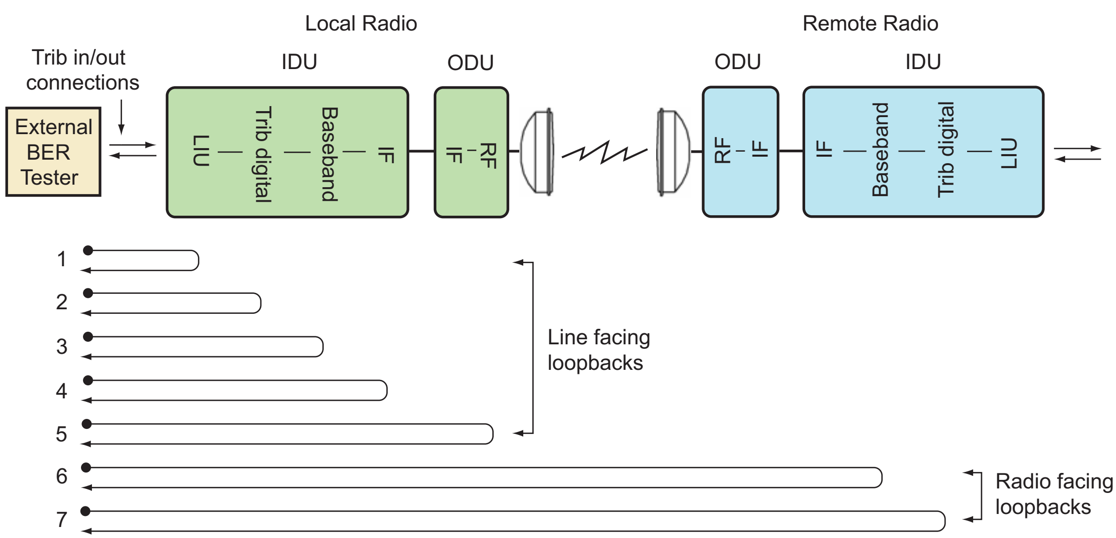


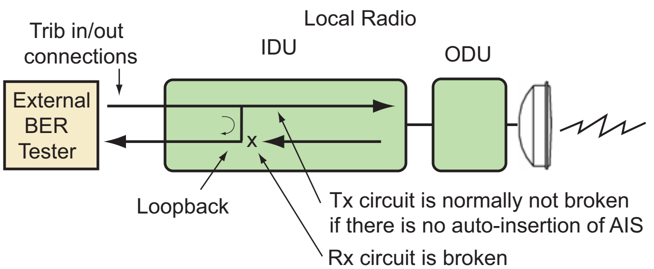
Table 9-2. Loopback Types and Applications

Legend	Loopback	Applications
1	Line facing LIU	Selected per tributary to check the tributary cables and the line interface unit (LIU) of the terminal.
2	Line facing tributary	Checks the selected tributary circuit prior to the traffic payload mux.
3	Line facing baseband	Provides a loopback at the digital baseband after the traffic payload mux. Loops all traffic.
4	Line facing IF	Provides a loopback on the IF side of the modulator/demodulator. Loops all traffic.
5	Line facing RF	Provides a loopback prior to the antenna feed point. Typically an RF loopback is enabled by setting the Rx to the same frequency as the Tx and using leakage across the diplexer to provide the receive input signal needed. At the same time the Tx at the remote end must be disabled. Another solution is to incorporate a built-in mixer just prior to the feeder flange to provide the required Tx to Rx coupling, which is especially relevant where high diplexer isolation prevents use of the former technique. • The RF loopback enables a complete check of a terminal, from the tributary input, to the diplexer, and back to the tributary output. • Use in conjunction with an IF loopback to confirm a problem in the RF transceiver, or for a split-mount radio, in the ODU or IDU/ODU cable. • Some split-mount radios may also incorporate a loopback within the IDU/ODU cable interface at the ODU to provide a separate cable check. • Additional loopbacks within an ODU would not normally be provided unless the ODU houses separate field replaceable units.
6	Radio facing baseband	Provides a digital baseband loopback on the remote radio. Loops all traffic. A remote loopback provides a check of the local radio, the radio path, and the remote radio up to the point of loopback.
7	Radio facing tributary or LIU	Sets a loopback on a selected remote tributary to provide a complete end-to-end link tributary check.

Loopback Guidelines

- Use loopback tests where a terminal is faulty and it is unclear where the fault is, based on front panel or craft tool alarm indications. Begin with the loop point closest to the BER tester, such as the tributary loopback, and work towards the RF loopback. The circuit between an OK loopback test and an errored or failed test is where the fault lies. Check the user manual to determine which cables and/or modules require checking, repair or replacement.
- Where a link is faulty, but still passing traffic, loopback checks can extend to the remote terminal.
- Where a network management system has control of tributary loopbacks and built-in trib BER testing, tests can be conducted across multiple links. This is especially useful in helping to locate the source of dribbling errors on a multi-hop circuit.
- When a loopback is applied it generally allows the outgoing signal to continue *unless* the radio has an auto AIS insert capability. Otherwise only the receive circuit is broken. Refer to Figure 9-2.

Figure 9-2. Typical Line Facing Loopback



- Where an AIS (Alarm Information Signal) is inserted it replaces the BER signal (or other signals) on the tributary outputs to indicate to the connected equipment that a diagnostic (alarm) mode has been applied to the alarmed circuit(s).
  - Where a radio has no internal BER generator/measurement function, the auto-inserted AIS would normally only appear at the remote radio tributary output(s).
  - Where a radio has an internal BER generator/measurement function, the auto-inserted AIS may appear on both the local radio and remote radio tributary outputs. Check manufacturer's data for details.
- When a loopback is applied, traffic is disrupted. For an LIU or tributary loopback, only the traffic on the selected tributary will be affected. For other loopbacks all traffic over the link will be affected.
- When a loopback is set, the radio should indicate on its front panel status indicators and in its alarm event log that a diagnostic mode has been selected.

- When checking a protected link, both ends of the link must be forced into the required A-side or B-side configuration, or combination thereof. This particularly applies to IF and RF loopbacks which if applied will cause a protection switch event.
- Loopbacks are normally provided with a time-out, meaning a loopback will be removed after a user-set time-out period. This feature is provided to ensure that normal operation will be returned in the event it is forgotten, or in the event an incorrect choice of loopback on a remote radio drops the path and therefore access to the remote radio.

When to Apply a Loopback Test

If traffic is errored and it is unclear if the problem is within the equipment or if it is path related, check the following before applying a loopback test:

- If both ends of the link are displaying a low RSL, the Tx power is normal at both ends, and there are no equipment alarms, then a path fade is indicated. Applying a loopback test is of little value except to confirm normal local radio operation via an RF loopback.
- If only one end is displaying an abnormal RSL then an equipment related problem is indicated. Check the Tx power at the remote end, and Rx performance and Rx alarms at the local end.

Fade Margin

A fade margin measurement provides an overall performance check of a link. As a troubleshooting aid the measured fade margin can be compared with the as-built (commissioning) figure to indicate current link health. Refer to Fade Margin on page 8-2 in Chapter 8. for guidance on fade margin measurement at commissioning.

The fade margin test measures the difference in receive signal level between the normal, operational level, and the threshold level, the level at which bit errors appear. The threshold level can be specified for a bit error rate (BER) of 10^{-6} or 10^{-3}.

The procedure requires the Tx power at one end of the link to be lowered to a point where receiver errors begin to appear at the other, as indicated by the 10^{-3} or 10^{-6} Rx threshold alarms, which may be read from the internal G.826 performance data, or from an external BER test-set in conjunction with a remote loopback.

The dB reduction in Tx power required should match the expected dB fade margin. This may require attenuation beyond the software adjustment limits for Tx power provided in the radio, in which case external attenuators will be required. This may be possible for an all-indoor radio, but not for a split-mount installation.

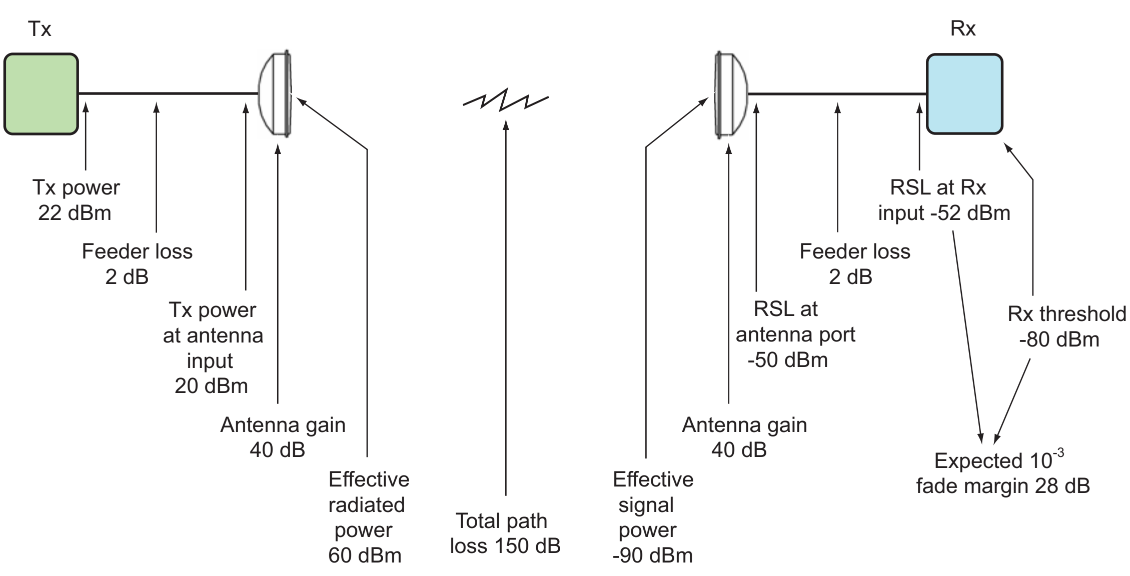
When comparing the current fade margin with the as-built figure, ensure the prevailing weather conditions are similar to those at the time of commissioning and that the same check procedure is used.

Fade Margin Computation

Figure 9-3 shows how the path gains and losses relate, beginning with the transmitter at the left and moving across to the receiver to the right. In this example the expected 10^{-3} fade margin of 28 dB can be verified by reducing the Tx power by the same dB value, at which point the onset of 10^{-3} errors should be apparent for a link where there has been no change in performance. However, the measurement accuracy is highly dependent on the accuracy to which the Tx power can be set, and the receive threshold established. An overall accuracy of 3 to 4 dB may be typical.

The expected fade margin may be sourced from the commissioning as-built records, or from the path planning data for the link.

Figure 9-3. Link Gains and Losses



If the measured fade margin is significantly lower than the as-built margin, the reasons for this can include:

- Equipment performance has reduced, which may be at either the transmit or receive end.
- Path conditions have changed (weather related or new obstacles)
- One or both antennas have moved out of alignment
- Problem with one or both antenna feeders, such a water entry into connectors.
- Interference from transmitters installed in the same geographical area

Tx Power Measurement

Where the transmitter output is suspect, a measurement of Tx power is required.

For split-mount radios, unless the ODU has a built-in measurement capability, in-situ measurement of Tx power is not possible. The ODU must be removed to a service center equipped with a test bench for the radio.

For all-indoor radios, field measurement is possible where access to the feeder permits insertion of an attenuator to allow connection of a power meter, or the insertion of a directional coupler to enable measurement of both forward and reverse power. Otherwise, the transmitter or transceiver section of the radio must be returned to a service center.

Feeder Return Loss

Where feeders for all-indoor radios are suspect, a return loss measurement is recommended. The measurement should be at the radio attachment point to include the complete feeder run and antenna.

Where return loss measurements were captured in the commissioning as-built records, measurement comparison will confirm the integrity of the feeder and antenna installation.

The most complete and convenient measurement solution is provided by a handheld, battery operated, microwave transmission line analyzer, which includes measurement of return loss, feeder loss and distance to fault (discontinuity). An optional power meter for power measurement is available with some instruments. For information on a typical analyzer refer to Waveguide and Coax Feeder Testing on page 5-20 in Chapter 5.

Other solutions for return loss measurement include a network analyzer, or a power meter in conjunction with a directional coupler.

Refer to Return Loss on page 3-13 for a definition of return loss.

Interference Measurement

Where interference is the suspected cause of link errors, a check for interfering signals can be made using a spectrum analyzer connected to the antenna or for an all-indoor radio, to its antenna feeder. Before doing so all other avenues of investigation should be explored, particularly so for a split-mount installation where connecting to its antenna is a difficult ‘tower-top’ process.

- For a split-mount installation, the ODU must be removed to gain access to the antenna port, and a flexible waveguide or waveguide-to-coax transition used to connect to a battery-powered analyzer.
- It is generally not practical to use the ODU/IDU cable to bring the RF signal down to the building (using a waveguide-to-coax transition at the ODU). The RG-8 style coax typically used should not be used at frequencies above about 2.5 GHz.

The check for interference should extend to cover 1st and 2nd adjacent channels on both sides of the link receive channel. The remote transmitter must be switched off for the duration of the test, except to provide a reference level measurement of the wanted signal. A comparison of the wanted signal to the level and frequency of the interfering signal or signals will assist analysis of the source of interference and corroboration of witnessed operational interference to the link.

Refer to the following section on co and adjacent channel interference for guidance on how to determine the significance of an observed interfering signal.

Co-Channel and Adjacent Channel Interference

The co-channel and adjacent channel figures for the link provide a guide to the required suppression of interference to achieve the receive performance specified for the radio in the presence of interfering signals.

If the interferer is within the same frequency channel as the received signal, it is referred to as co-channel interference. If the interferer is of a level comparable to or larger than the wanted signal, then the interferer will dominate and the link will fail.

If the interferer is close to the received signal, but not co-channel, it is referred to as adjacent channel interference. If the interferer is one channel spacing away, it is referred to as a first adjacent channel interferer. At this spacing, the receiver is far more tolerant to interference, and can cope with much larger interference than at co-channel frequencies.

The level of interference that a radio can tolerate for co-channel or adjacent channel interference is specified as a C/I value (carrier to interferer ratio), or as W/U (wanted to unwanted), which are the same and are measured in dB. ETSI define the criteria for the measurement as the level of interferer that will degrade the bit error rate of an operational link running at 1×10^{-6} BER by one order of magnitude to 1×10^{-5} BER. The limits for radios of different data rates are

identical, varying only with the modulation of the radio. Example co-channel and adjacent channel figures for a radio with QPSK and 16QAM modulation options are shown in Table 9-3 on page 9-15.

Table 9-3. Example Co-Channel and Adjacent Channel Figures

Modulation type	Co-channel C/I	1st adj. channel C/I	2nd adj. channel and greater C/I
QPSK	23dB	0dB	-25dB
16QAM	30dB	0dB	-25dB

In this example, if the link was set to operate in QPSK mode at its 10^{-6} receive threshold (say -80 dBm), a C/I of 23dB means that the carrier should be 23dB greater than the interferer, meaning that if the interferer is lower or equal to -107 dBm, then the link will be operating no worse than 10^{-5} BER.

Similarly, for the 1st adjacent channel a C/I of 0 dB can be tolerated, meaning that if the interferer is lower than or equal to 0 dB (up to the same signal level as the carrier), then the link will be operating no worse than 10^{-5} BER.

For the 2nd adjacent channel a C/I of -25 dB can be tolerated, meaning that an interferer up to 25dB larger than the wanted signal can be tolerated.

In practice, proper path planning and antenna polarization should ensure that there are no significant interferers within the co and 1st adjacent channels.

Interference Rejection Factor (IRF)

The Interference Rejection Factor (IRF) is the amount of interference a link can tolerate from an interfering signal but differs from co and adjacent channel measurements in two respects:

- IRF describes the interference between signals of different channel bandwidths and offsets.
- IRF is given relative to the co-channel interference level (co-channel C/I).

The IRF differs for different modulation signals, such as QPSK, 16QAM, and 64QAM. Table 9-4 on page 9-16 shows the IRF for a QPSK or 16QAM link being interfered with by interferers with bandwidths ranging from 0.5 MHz to 7 MHz, and at offset frequencies ranging from 0 MHz to 14 MHz.

Table 9-4. Example IRF Table

Signal Ch BW	Interferer BW	Frequency[1]						
		0MHz	0.5MHz	1MHz	2MHz	3.5MHz	7MHz	14MHz
3.5MHz	0.5MHz	0	0	1	15	50	>60	>60
	1MHz	0	0	1	3	45	>60	>60
	2MHz	0	0	1	2	40	>60	>60
	3.5MHz	0	0	1	2	30	50	>60
	7MHz	0	0	0	1	2	40	>60
7MHz	0.5MHz	0	0	0	1	25	55	>60
	1MHz	0	0	0	1	15	50	>60
	2MHz	0	0	0	1	3	45	>60
	3.5MHz	0	0	0	1	2	40	>60
	7MHz	0	0	0	1	2	30	50

1. The figures below the frequency columns are in dB and reflect the level of interference relative to the co-channel C/I figure that the radio can tolerate before the onset of BER degradation.

For example, what level of interference can be tolerated by a 4xE1 16QAM radio operating in the presence of a 1 MHz wide interferer located 2 MHz away?

The link channel is 3.5 MHz wide (4xE1 and 16QAM).

Table 9-4 shows that with a 1 MHz bandwidth interferer centered 2MHz away, the link has an IRF of 3 dB. This means that the interferer can be up to 3 dB higher in level than the co-channel C/I figure for the link, before BER degradation becomes noticeable.

From Table 9-3 on page 9-15 the co-channel C/I ratio for 16QAM modulation is 30 dB (interferer must be no higher than 30 dB below the link signal level), therefore, in this example, the 1 MHz wide interferer 2 MHz away must be no higher than 27 dB below the link signal level.

Bench Testing

Bench testing refers to testing a radio at a service center using test jigs and test instruments recommended by the equipment manufacturer. It especially applies to split-mount radios to support off-site IDU and ODU terminal and link testing.

Bench testing can be used to:

- Pre-configure and test a link before it goes into service.
- Test suspected faulty equipment or equipment modules returned from the field to confirm a fault, or no-fault-found.
- Test spares and repaired items before they are put into service.
- Upgrade spares and repaired items to the latest SW build level before they are put into service.

A typical bench for a split-mount link would include:

- Mechanical supports for two ODUs.
- Fixed and variable waveguide attenuators and short sections of flexible waveguide to simulate the link path.
- IDU/ODU cables.
- Tributary cables.
- Power supply.

The test equipment typically required to support such a bench includes:

- The craft tool for the radio.
- BER test-set.
- Power meter.
- Spectrum analyzer.

For network operators with a medium to large investment in a particular radio, such a bench has real value at the network roll-out phase and in the subsequent management of service returns from the field, and of repaired items returned from the manufacturer. It also provides a ideal training facility for installation and service engineers.

Fault Reports

Good fault reporting and report management is essential for cost efficient management of the network, the spares holdings, and of the service team.

The reports should include:

- Date and time of fault notification.
- Time of arrival at site.
- A listing of front panel alarm and status indications.
- What was checked to confirm the suspected fault.
- What work was done to fix the fault.
- What spares were used by type and serial number.
- Time of service restoration.
- What items were returned to base for repair by type and serial number.
- A field in which relevant comments on the equipment or the site can be entered.

Fault reports should be reviewed by service management and as appropriate used to provide:

- Details of the fault found to accompany items returned to the manufacturer or their service agent for repair.
- Trend analysis. Is there a pattern of common faults, which suggests either a weakness in the equipment, the way in which it has been installed, or perhaps a problem with the initial path planning, such as an inadequate rain-fade margin.
- Spares holdings. Are they adequate and held at the best locations for access. Are they excessive and if so can the excess be transferred to installation stock.
- Do the reports indicate areas where preventative maintenance may provide service benefits.
- Do the reports indicate any weakness in the initial operations center identification of a fault, its location, and the information sent to the service engineers.
- Do the reports indicate any weakness in the training provided to service engineers, or in the sharing of relevant service data captured on-the-job.

Appendix A. Site Survey Formset

This appendix introduces the Excel-based suite of pre-installation site survey forms available from HSX. They can be used as-is, or as the basis for preparing user-specific forms.

The forms provided are:

- Site Survey Checklist on page A-1
- Ground and Lightning Protection Checklist on page A-7
- Pre-Install Checklist on page A-17

Excel files for the Survey Formset and for its companion Installation and Commissioning Formset are available from HSX or HSX suppliers. Contact a HSX Helpdesk for assistance.

Site Survey Checklist

This checklist is intended for use during a site survey to help ascertain the readiness of a site for a new installation.

If the site is lightning prone, complete a Site Grounding and Lightning Protection Checklist. Refer to Ground and Lightning Protection Checklist on page A-7.

The Survey Formset file includes both PC and hardcopy forms. The PC version is designed for direct PC entry of data; the hardcopy version for printing and clip-board entry. The hardcopy version is shown in Figure A-1 through to Figure A-5.

Figure A-1. Site Survey Checklist, Hardcopy Page 1

Company Name

Site Survey Checklist

Site:	
Surveyed by:	
Date:	

Item	Response	Check
Site Data		
Site address:		
Site co-ordinates:		
Site owner:		
Site contact:		Specify the name and full contact details (including after-hours) for the person responsible for the site (site owner representative).
Site access & security:		1) Specify all site access and security procedures. 2) Check if the site owner has any preferences or requirements on the selection of riggers (contractors) for on-tower work.
Site parking:		On site parking availability.
Site health & safety:		Are there any obvious health and safety issues at the site, such as RF hazards (radiation from installed antennas), electrical hazards, slippery surfaces, chemical hazards etc.
Site storage:		Is there adequate on-site storage space for the equipment to be installed, and how secure is it.
Building Data		
Building type:		1) Single or multistory. 2) Purpose-built equipment room or otherwise.
Building access:		Note any special building access requirements.
Equipment room OK yes/no:		1) Is it a purpose-built equipment room. 2) Is the ventilation OK. 3) Is access to the room controlled/restricted.

Figure A-2. Site Survey Checklist, Hardcopy Page 2

Environmental

Earthquake prone site yes/no:		If yes, special attention to equipment anchoring will be needed.
Coastal or other corrosive atmosphere yes/no:		If yes, extra attention to anti-corrosion measures may be needed for the exposed equipment such as antennas, lightning surge suppressors, connectors, ground connection points and ODUs.
Exposed to high winds yes/no:		If yes, this may affect the choice of antenna, its mount and bracing. High winds may also affect installation scheduling.
High ambient temperatures:		If the site is subject to periods of high ambient temperatures Check that: 1) Adequate cooling (aircon or fans) is provided for the equipment room. 2) If also a high solar-gain site, note if a sun-shade for the ODU (split-mount installations) should be considered.
Access in all seasons:		Note the expected impairment to site access during seasonal rain, snow and ice.

Path and Link Data

Number of hops required to/from this site:		
Far end site references and co-ordinates:		List far-end site name(s) and grid references.
Path length(s):		
Required antenna height(s):		List the required height on the structure for each antenna.
Azimuth to far end(s):		Compass bearings (magnetic or true north).
Path profile status:		1) If path profile(s) have been completed, do they support use of the site. 2) If not completed, or if further checks are required, explain status.
Link equipment model, capacity, configuration and manufacture:		List the radio link equipment to be installed and its protection configuration.

Figure A-3. Site Survey Checklist, Hardcopy Page 3

Antenna Mounting & Support Structure

Structure type, model and manufacturer:		Self supporting tower or, Guyed mast or, Monopole or, Rooftop or, Side of building or, Other (describe)
Required mount locations OK yes/no:		Are suitable mount locations available on the structure for the required height(s) and azimuth. Note the antenna offset to be used (left or right viewed from the rear of the antenna).
Mount type & requirements:		Specify type of mount required: 1) Std tower-type pipe mount. 2) Custom mount. Detail the requirement, such as rooftop, parapet or wall mount and note the fastening/anchoring required, such as anchor bolt to a brick wall, or a non-penetrating roof mount
Mount provided and installed by:		Specify who best to design, supply and install the mount.
Antenna hoisting requirements:		Where a hoist is required, indicate the type (manual or powered winch) and if there are any apparent winch location difficulties.
Installation safety:		Note if any special precautions are indicated during the installation of the antenna and its mount, such as a need to close off of a section of footpath or roadway below the structure, which may require a permit from a local authority.
Antenna protection:		Note any special protection needed, such as for ice fall.

Feeder Cable

Type of feeder or IDU/ODU cable required:		
Feeder routing OK yes/no:		Are there any unusual feeder routing, fastening and support issues.
Feeder length(s) required:		State the cable run lengths required.
Feeder protection required yes/no:		Note any special protection needed, such as for ice-fall, or conduit for other localized protection.
Feeder attachment to structure:		Note how the feeder or IDU/ODU cable is to be fastened to the antenna structure and cable bridge. If cable hangers are to be used specify the type of adaptors needed to attach to the structure.
Location for lightning surge suppressors:		For coaxial feeders and IDU/ODU cables note where the suppressor(s) should be installed
Feed-through:		Note if an existing wall or roof feedthrough can be used. If not, specify the required type and indicate where and how it can be installed.

Figure A-4. Site Survey Checklist, Hardcopy Page 4

Site Grounding & Lightning Protection

Single or multipoint grounded:		If not single point grounded and/or there are grounding or lightning protection issues, complete a Ground and Lightning Protection Checklist.
Antenna at highest point on structure yes/no:		If located at the highest point additional lightning protection may be needed, such as installation of a lightning finial.
Lightning prone site yes/no:		If yes, complete a Ground and Lightning Protection Checklist.
History of lightning damage at site yes/no		If yes, complete a Ground and Lightning Protection Checklist.

Power Supply

Power supply requirements:		Specify AC and/or DC voltage and current requirements, and DC polarity.
Existing or new PSU:		1) If existing, has it the power reserve needed. 2) If new, specify the capacity and type required, and its possible location.
Existing or new fuse/breaker panel:		1) If the existing panel is to be used, note the fuse/breaker type needed. 2) If a new panel is to be installed, check the type needed and its possible location.
Cable capacity and routing:		If power is to be taken from an existing rack fuse panel, check that the wiring to the panel and main power supply fusing has the required capacity to handle the extra load.
Safety OK yes/no:		Does the existing power supply or primary power source meet current local authority installation requirements.

Radio/Mux Equipment Installation

Existing rack(s):		Specify equipment location in the rack(s). Check rack anchoring, bracing and grounding.
New rack or cabinet:		1) Specify the type of rack or cabinet needed and how it should be anchored/braced. 2) Note the type of floor material used (for anchoring purposes). 3) Note any special requirements if the site is earthquake prone. 4) Note if the rack/cabinet needs to be fitted with an insulating base to isolate it from an earth-contact floor (for single-point grounded sites).
Ambient temperature and airflow OK yes/no:		Check that ambient temperature limits for the equipment to be installed will not be exceeded. If the installation is to be within an existing cabinet, check: 1) That the ambient within the cabinet is not excessive. 2) That with the new installation, the extra heat generated is unlikely to result in an excessive ambient within the cabinet. 3) If the equipment to be installed is fan cooled, that its intended location will not impair fan in/out airflow. 4) If the equipment to be installed requires clear rack space above and/or below, that the additional space is available.

Figure A-5. Site Survey Checklist, Hardcopy Page 5

Other Equipment

Dehydrator:		Where feeders must be connected to a dehydrator, specify: 1) If an existing or new installation is to be used. 2) If new, indicate the required type and its possible location. 3) If any non-standard air-plumbing is indicated.
Patch panel:		1) If an existing patch panel or customer termination is to be used, note its location and the ports available for use. 2) If new, indicate the type required and its possible location.
Other:		

Remedial Work

List remedial work required at site:		List all remedial work required before or during the planned installation. Where this work needs to be done by, or agreed by the site owner, note the actions required.

Support Services Required

Electrical:		Specify the work required.
Rigging:		Outline the type of rigging services required.
Other:		Such as a roofing contractor where a roof-top mount is required

Planning Approvals & Permits

Site:		Note if there is: 1) A restriction on the type of antenna and its position to meet a visual impact bylaw. 2) A permit or license needed to allow RF radiation from the site.
Installation:		Note if there is an approval or permit required before the installation work can proceed. This may apply where pedestrian safety is an issue during work on a tower, or on the side or parapet of a building.
License:		Note the status of the link license(s), where required. In particular, what still needs to be checked or approved before a license application is submitted.

Plans and Maps

Site plan attached yes/no.	
Area map attached yes/no:	

Additional comments:

Ground and Lightning Protection Checklist

This section describes a survey procedure and checklist for use when determining the adequacy of existing protection measures at a site. The checks should be conducted as part of a pre-installation site survey.

The survey describes a strategy for new installations followed by a seven-step check procedure and a checklist into which check results can be entered. Refer to:

- Installation Strategy for a New Installation on page A-7
- Seven-step check procedure comprising:
  - 1 Lightning Prone Location on page A-8
  - 2 History of Lightning Damage at Site on page A-8
  - 3 Site Grounding on page A-9
  - 4 Single Point Grounding on page A-9
  - 5 External Ground Connections on page A-10
  - 6 Feeder and ODU Cable Grounding on page A-11
  - 7 Internal Ground Wire Connections on page A-12
- Site Grounding and Lightning Protection Checklist on page A-13

Installation Strategy for a New Installation

This strategy sets out the points of reference to assist in deciding whether or not a new installation should proceed and if so what, if any, remedial action should be taken beforehand.

- If the site has a recent history of equipment failures due to lightning strikes and the affected equipment has been correctly installed, then new installations should not commence until reasons for the failures have been identified and the causes remedied. Failure to do so may void the supplier's warranty on the newly installed equipment.
- If the site is lightning prone but has no history of strike damage to installed radio equipment, then a new installation may commence providing the basics for good site grounding are met. This should mean:
  - The site has single point or full perimeter grounding, or if not, the site has good internal bonding between all ground attachment points.
  - External ground connections for the tower and at building entry are visually correct, and where measurement of ground resistance is possible, that readings are within limits.

- Existing installations have their feeders or ODU cables correctly grounded on the tower, at the point of leaving the tower and just prior to building entry.

If the basics are not met, an installation should not proceed until the supplier and the operator and/or site owner have satisfied themselves that the areas of non-compliance do not represent a threat to the reliable operation of the equipment.

1 Lightning Prone Location

What to Check

Check whether the location is a lightning prone; does it experience thunderstorms on more than 25 days a year?

Procedure

If a lightning prone site, check and record the number of thunderstorms typically experienced per year and their severity:

- Check local weather records.
- Check with other site users.
- Check with local/regional authorities.

If it not a lightning prone site, tick **No** on the checklist.

2 History of Lightning Damage at Site

What to Check

Ask the site owner, operators, and/or installers about lightning damage at the site. If there has been lightning damage, ask the following questions:

- How often do strikes occur and how often is equipment damaged?
- When was the last equipment failure?
- What was the failure mode?

If there is a damage history then regardless of the adequacy of existing grounding and protection mechanisms in place, attention to lightning protection is needed before starting the installation.

- If the site appears to be correctly grounded (single point ground and a full tower/site ground system), and the affected equipment has had suitable lightning surge protectors fitted, then a site inspection by a certified lightning protection and ground system consultant is recommended, especially if the adequacy of ground system is suspect and/or the site is particularly lightning prone.

- If the site is not single point grounded and/or existing ground connections and bonding are suspect, these must be addressed prior to, or during any new installation.

Procedure

If there is a history of damage, check and record the following:

- The frequency of damage
- The type of damage
- When damage was last reported.

If there is no history of damage, tick **No** on the checklist.

3 Site Grounding

What to Check

Check to see if a suitable tower/site ground system has been installed.

Procedure

Refer to original site installation records. A typical system will have at least 70m (200 ft) of buried ground conducting wire with a minimum of five paths leading away from the tower base, each of 14m (40 ft). If the ground is a poor conductor, additional measures should have been provided to ensure a low resistance path to earth.

If suitable site grounding has been installed, tick **Yes** on the checklist.

If the grounding is not satisfactory, tick **No** on the checklist and list your concerns.

4 Single Point Grounding

What to Check

Is single point grounding employed? Is all equipment within the building grounded at a master ground bar at the point of feeder/ODU cable entry to the building?

Procedure

Visually inspect the building ground. Single point grounding has all equipment within the building at the same ground potential to ensure there is no possibility for damaging currents to flow between the equipment or through the equipment to ground.

The single grounding point should be at a master ground bar installed at the feeder/ODU cable point of entry to the building. In turn the master ground bar

should be connected to the tower/site ground by heavy copper strap or wire.

Effective single point grounding can also be achieved where there are multiple ground connections into the building *providing* these grounds are directly bonded to a common perimeter ground for the building.

- Single point means all mains power, external telco and other radio and communications equipment use the common ground, and that there is no other ground connection for equipment installed within the building.
- If the building has a concrete floor in direct contact with the ground, then equipment such as racks and power supplies should not be anchor-bolted directly to the floor unless the site has a correctly installed perimeter ground. Otherwise such floor anchoring will defeat the single point ground. In such instances the equipment can be isolated from the floor using suitable insulating plinths or pads.

If single point MGB grounding or full perimeter grounding is installed, tick **Yes**.

If single point MGB grounding or full perimeter grounding is not installed, tick **No** and describe the grounding at the following points:

- Cables at entrance to the building
- Racks, include whether or not the racks are anchor bolted to a ground-contact concrete floor
- Mains power supply
- Telco lines

5 External Ground Connections

What to Check

Check the following:

- Main tower/mast grounds
- Guy wire grounds for guyed masts
- Cable tray/carrier grounding
- Building entry ground bar (MGB)
- Perimeter fence and gate grounds

Procedure

Visually inspect all ground connections:

- Ensure all connections are tight, free from corrosion, and are corrosion protected with suitable grease/paint

- Check that the ground wires/straps are of a suitable size and are in good physical condition
- Check that the ground wires/straps go directly to ground (not looped or spiraled)

Take measurements of existing ground connections where possible:

- A 3-point test will provide a reliable indication providing the ground conductor can be isolated from the equipment and /or tower, which in most instances will not be permitted for an operating site. In these situations a clamp-on resistance tester can be used, providing the ground wire/strap location and size permits clamp-on access.

If the external grounding is satisfactory, tick **Yes**.

If the external grounding is not satisfactory, tick **No** and describe the existing grounds and the required remedial action for the following. Include ground resistance measurements where possible and compare with any as-built records:

- Main tower/mast grounds
- Guy wire grounds
- Cable carrier ground(s)
- Building entry ground bar (MGB)
- Perimeter fence and gate grounds

6 Feeder and ODU Cable Grounding

What to Check

A check of all existing waveguide/coax feeders and ODU cables to ensure they have grounds correctly located on the tower and at building entry, and that their ground-wire connection points are tight, not corroded and suitably protected by conductive grease or protective paint.

Procedure

Visually inspect the grounds. If not correctly installed or their ground connections are suspect they can result in the feeder/ODU cable being a conduit for lightning induced surges to the rack(s), and in the process significantly reduce the protection provided for other equipment in the same rack(s); equipment which does have a correctly grounded feeder/cable.

- Before commencing an installation, the incorrectly grounded feeders/cables must be properly grounded. For correct grounding a ground kit is required at the following locations:
    - At the top of the cable run where the cable branches off the tower to the antenna/ODU

- At the base of the tower where the cable branches off to the building
- At the point of entry to the building.
- Where the cable run on a tower exceeds 30m (100ft), a cable ground should be fitted at not more than 30m intervals.

If existing feeder/cable grounds are satisfactory, tick **Yes**.

If existing feeder/cable grounds are not satisfactory, tick **No**, and describe the deficiencies and remedial action required at:

- On the tower
- Tower departure
- Building entry (grounding to the MGB)

7 Internal Ground Wire Connections

What to Check

Check that all equipment within the building is correctly grounded.

Procedure

Visually inspect all ground wire connections from the MGB to equipment racks, power supply and telco equipment. Measure resistances between installed equipment and the MGB, which must all be less than 1 ohm, and preferably not more than 0.5 ohms.

Where single point grounding has not been installed[1], and where a change to single point grounding is not practical, then good ground bonding between installed equipment, and from equipment to ground is especially important to minimize the impact of high current flows between ground points (due to strike induced voltage gradients in the ground). In particular:

- Ensure there is direct bonding using large diameter (minimum 21 mm^2, 4 AWG) wire between the different ground attachment points, such as the building entry ground bar (MGB), the AC mains ground, and telco ground.
- Wire runs must be as direct as possible and connect between each point directly - do not connect in series. Bear in mind that what is needed is a ground-ring inside the building.

Racks must be separately grounded from their ground bars to the MGB, using minimum 16 mm^2, 6 AWG ground wire, and follow the same route as the feeder/ODU cables. Rack ground bars must be located at the top of a rack for top-entry feeder/ODU cables, or at the bottom for bottom-entry raised floor installations, and the radio equipment installed accordingly; top-down for top-entry cables,

1 The AC and/or telco grounds are not bonded to the site/tower ground. Instead their grounding is provided by separately installed ground rods or similar.

and bottom-up for bottom-entry.

Check that equipment installed in racks is correctly grounded to its rack ground bar. This is especially applicable to equipment that is to be connected to in the new installation, such as for trib or auxiliary services inter-connections.

If ground wiring within the building is satisfactory, tick **Yes**.

If ground wiring is not satisfactory, tick **No** and describe the existing grounding and the required remedial action for the following. Include resistance measurements for the following and compare with any as-built records:

- Grounding between the Radio, AC and Telco grounds
- Rack(s) to ground
- Rack-to-rack
- Equipment within racks

Site Grounding and Lightning Protection Checklist

The following checklist is intended for use at existing sites, but may also be used as appropriate at new sites to check the adequacy of grounding and lightning protection measures.

The checklist lists the checks and summarizes actions required. It should be read in conjunction with check and procedures guide beginning with step 1 Lightning Prone Location, on page A-8.

Where there are significant areas of non-conformance or concern, these must be addressed prior to the commencement of a new installation. Refer to Installation Strategy for a New Installation on page A-7 for points of reference.

The Excel-based Survey Formset includes editable PC and hardcopy versions of this checklist. The hardcopy version is displayed in Figure A-6 through to Figure A-8.

Figure A-6. Ground and Lightning Protection Checklist, Hardcopy Page 1

Company Name

Ground and Lightning Protection Checklist

Site:	
Inspected by:	
Date:	

Item	Response	
Lightning prone location	☐ **Yes** ☐ **No**	Indicate the number and severity of thunderstorms typically experienced per year.
History of lightning damage	☐ **Yes** ☐ **No**	Describe frequency of damage, the nature of the damage and when damage was last reported.
Is a proper site ground system installed - confirmed by site installation records	☐ **Yes** ☐ **No**	Describe any deficiencies in the installed site ground system, or if no installation record is available.
Is single point MGB grounding or full perimeter grounding installed	☐ **Yes** ☐ **No**	Describe existing grounds for: a) Waveguide/coax feeders and ODU cables at the entrance to the building. b) Racks. Include whether or not racks are anchor-bolted to a ground-contact concrete floor. c) AC mains into the building. d) DC power supply. e) Telco lines.

Figure A-7. Ground and Lightning Protection Checklist, Hardcopy Page 2

Is external structure grounded	☐ **Yes** ☐ **No**	Describe and list any remedial action for the following. Include ground resistance measurements and where possible compare with as-built records: a) Main antenna support structure (tower, mast etc.) b) Guy wire grounds. c) Cable carrier grounds. d) Building entry ground bar (MGB). e) Perimeter fence and gate grounds. f) Grounding for existing feeders and ODU cables.
Are existing feeders and/or ODU cable grounds OK	☐ **Yes** ☐ **No**	Describe and list any required remedial action required for grounds at : a) Structure departure (where cables or waveguide branch off a tower/mast towards the equipment room. b) Building entry (grounding to the MGB).

Figure A-8. Ground and Lightning Protection Checklist, Hardcopy Page 3

Is equipment grounding within the building OK Special attention to bonding is required if single point or perimeter grounding has not been installed.	☐ **Yes** ☐ **No**	Describe and list any required remedial action for the following. Include resistance measurements and where possible compare with as-built records: a) MGB to rack(s). b) MGB to PSU. c) MGB to AC mains ground. d) MGB to Telco grounds. e) Rack-to-rack. f) Equipment within racks.

Additional Comments

Pre-Install Checklist

The Pre-Install Checklist is an “aid memoir”. It covers check-points typically required in the lead-up to a new installation. Its layout is shown in Figure A-9 on page A-17.

Figure A-9. Pre-Installation Checklist

Company Name

Pre-installation Checklist

Project reference:	
Link reference:	
Sites:	
Link model and capacity:	
Antenna type and size:	
Other equipment to be installed:	

Item	Detail	Check Box
Sites ready	Site owner work completed	
	Contractor work completed	
Permits and licenses	Site Access	
	Local authority planning	
	Local authority safety	
	Link license	
	Software (link capacity license)	
	Personnel (rigging)	
Safety issues	Any on-site personnel safety issues identified and qualified	
Accommodation (if required)	Hotel or other lodgings confirmed	
Contractors (if required)	Your contractors are confirmed	
Directions and site and building access keys	Map	
	Keys or security code	
Installation datapack	Is complete in required detail	
	Includes NMS configuration data (IP addressing and routing)	
	Includes a commissioning checksheet	
Equipment verification	All equipment to be installed is correct and complete	
	Required accessories are correct and complete	
	Tx high / Tx low ends are correctly identified per site	
	Spare equipment	
Bench test (optional)	Confirm correct link operation	
Tools	All required installation tools	
Equipment	Such as a winch/hoist or trenching machine	
Consumables	All required / expected consumables	
Test equipment	All required test equipment	
Weather	The forecast weather will not impact the installation	
Contacts list	Project manager	
	Site owner	
	NOC	
	Tech support	
Other		

Appendix B. Installation and Commissioning Formset

This appendix introduces the Excel-based suite of installation and commissioning forms available from HSX. They can be used as-is, or as the basis for preparing user-specific forms.

The forms provided are:

- Installation Datapack on page B-1
- Racking on page B-4
- Circuit Connections on page B-5
- Commissioning Form on page B-6
- Installation Inspection Report on page B-8
- Acceptance Form on page B-9
- Remedial Action Form on page B-10

Excel files for the Installation and Commissioning Formset and for its companion Site Survey Formset are available from HSX or HSX suppliers. Contact a HSX Helpdesk for assistance.

Installation Datapack

The Installation datapack provides a prompt for capturing information typically required by an installer to install a new link. It is presented as an Excel file with mouse-over comments and links to supporting files where appropriate. Its layout is shown in Figure B-1 and Figure B-2.

The Excel formset also includes a filled-out example of the Installation datapack.

Figure B-1. Datapack, Page 1

Company Name

Link Installation Datapack: Split-Mount Radio

Project reference:	
Link reference:	
Issued by:	
Issued to:	
Date:	
Link license:	

Start date:	
Required hand-over date:	

Link model & manufacture	
Protection mode	
Capacity	
Frequency band	
Hop distance	
Expected fade margin(s)	

Mouse-over comments are included where appropriate. For further guidance refer to the Datapack Example

Project contact:	
Tech support contact:	
NOC contact:	

Scope of Work	
Equipment provided by company	
Items to be provided by installer	

Site Data	**Site A**	**Site B**
Site name		
Site address		
Site co-ordinates		
Site contact		
Site access & security		
Building access & security		
Site parking		
Site health & safety		
Environmental Issues		
Site storage		
Site permits		

Installation Data

Outdoor installation		
Antenna support structure		
Antenna pole mount location		
Antenna type and model		
Antenna offset		
Antenna azimuth		
Antenna polarization		
ODU / antenna connection type		
IDU / ODU cable type		
ODU / IDU cable connector		
Cable fastening		
Lightning surge suppressors		
Ground wires		
Other		

Figure B-2. Datapack, Page 2

PSU installation

PSU model & manufacture		
DC voltage, polarity and rating		
Location		
Anchoring		
Grounding		
AC connection		
Battery backup		
DC connection		

Rack installation

Rack model & manufacture		
Location		
Anchoring		
Grounding		
Fuse panel		

Terminal installation

Racking	Refer to Racking sheet.	Refer to Racking sheet.
Grounding		
Other		

Terminal configuration data

Terminal name		
Capacity / modulation / bandwidth		
Tx frequency		
Rx frequency		
Split		
Tx power		
ATPC settings		
RSL / RSSI expected		
Circuit connections	Refer to Circuit Connections sheet	Refer to Circuit Connections sheet
Alarm limit settings		

Protection configuration

Protection mode		
Splitter/combiner losses		
Online Terminal (A side)		

Engineering Orderwire

Configuration		

Software version required

Terminal/system:	
Craft tool:	

NMS configuration

IP address & mask		
Routing		
Network connection		

Labelling

IDU / ODU cable		
Rack		
Terminal		
Trib cables		
NMS cable		
Fuse/breaker panel		
Fuse/breaker		
PSU		

Racking

The Racking form provides a visual guide for where new equipment is to be installed in a rack. Its layout is shown in Figure B-3.

Figure B-3. Racking Data

Racking Data

Project reference	
Link reference	
Site A name	
Site A terminal	
Site B name	
Site B terminal	
Date	

	Site A*		Site B*
44	Breaker panel	44	Geerad breaker panel
43		43	
42		42	
41		41	
40	Existing microwave link	40	RXN : Terminal No. E34
39	installations	39	
38		38	
37		37	
36		36	
35		35	
24		24	
33		33	
32		32	
31	RXN : Terminal No. E33	31	
30		30	
29		29	
28		28	
27		27	
26	Patch panel NxE1	26	Patch panel NxE1
25		25	
24		24	
23		23	
22		22	
21		21	
20		20	
19		19	
18	Existing GSM installation	18	New GSM installation
17		17	
16		16	
15		15	
14		14	
13		13	
12		12	
11		11	
10		10	
9		9	
8		8	
7		7	
6		6	
5		5	
4		4	
3		3	
2		2	
1		1	

*Use the Text Box facility to insert and describe racked components. Green fill indicates new installation.

Circuit Connections

The Circuit Connections form supports capture of circuit (trib) interconnection data. Its layout is shown in Figure B-4.

Figure B-4. Circuit Connections Form

Company Name

Circuit Connections

Project reference	
Link reference	
Date	

	Site A	Site B
Trib type		
No. of tribs connected		
Cable & connector type		

Connections

Trib No.	Site A			Circuit Name	Site B		
	In/Out*	Connect To	Trib Cable Label		In/Out*	Connect To	Trib Cable Label
1	In				Out		
	Out				In		
2	In				Out		
	Out				In		
3	In				Out		
	Out				In		
4	In				Out		
	Out				In		
5	In				Out		
	Out				In		
6	In				Out		
	Out				In		
7	In				Out		
	Out				In		
8	In				Out		
	Out				In		
9	In				Out		
	Out				In		
10	In				Out		
	Out				In		
11	In				Out		
	Out				In		
12	In				Out		
	Out				In		
13	In				Out		
	Out				In		
14	In				Out		
	Out				In		
15	In				Out		
	Out				In		
16	In				Out		
	Out				In		

* Trib-in / trib-out of radio

Commissioning Form

The Commissioning form supports capture of typical link commissioning test and performance data. Where appropriate, guidance is provided on the check process. Its layout is shown in Figure B-5 and Figure B-6.

Figure B-5. Commissioning Form, Page 1

Company Name

Link Commissioning Form

Project reference	
Link reference	
Site A name	
Site A terminal	
Site B name	
Site B terminal	
Commissioning engineer	

Link ready for traffic yes/no		If not ready, or there are unfinished items, explain in Comments box below.
Signed		
Date		

Link Checks	Specification	Results	Process
Circuit connections	Each trib connected correctly end-to-end		Apply a physical loopback to each trib in turn at the Site B patch panel and confirm using a BER tester at the Site A patch panel.
Circuit BER	No errors		Run an overnight BER test on looped circuit 1.
Link BER	No errors		Monitor Site A and Site B G.826 error count overnight.

Site/Terminal Checks	Specification	Results Site A	Results Site B	Process
Fade margin	X dB +/- 2 dB			Reduce the local Tx power until the remote Rx indicates a 10^{-6} threshold alarm. (For split-mount radios this test may not be possible due to insufficient Tx power adjustment range and an inability to insert additional attenuation).
ATPC operation	See process			Confirm correct setting. Confirm normal operation by noting existing Tx power and then disabling Rx at the remote end and checking that local Tx power increases to ATPC max. (For a protected link first apply a protection switch lock).
Alarm limits	Setting +/- 2 dB			Confirm correct setting and operation for any Tx power & Rx level alarm limits.
LED indications	See process			Confirm that the expected alarm and status LEDs occur during the commissioning tests.
DC supply voltage	X Vdc +/- 5%			
DC supply battery backup	See process			Confirm correct switchover to battery and restoration. Run on battery for 4 hours.
EOW	See process			Confirm operation to each end and to the NOC
NMS	NOC routed			Confirm both ends are NOC viewable

Figure B-6. Commissioning Form, Page 2

Protected radio tests

A to B side Tx switching	Traffic restored within 2s			
B to A side Tx switching	Traffic restored within 2s			
A to B side Rx switching	Hitless			
B to A side Rx switching	Hitless			
Confirm correct unequal loss splitter assignment	Low loss side to Tx A			

Serial and version numbers

Antenna			
ODU			
IDU			
System software			
PSU			

Ground checks

Master Ground Bar resistance	Max 0.5 ohms		
Rack to MGB resistance	Max 0.5 ohms		
PSU to MGB resistance	Max 0.5 ohms		
Tower ground resistance(s)	Max 0.5 ohms		
Other resistance readings			

Test equipment used

BER tester	
Ground restance tester	
Other	

Prot. & alarm status on exit	A Side Tx and No alarms		

Comments:

Installation Inspection Report

The Installation Inspection Report supports a site-based inspection of a newly completed installation. Its layout is shown in Figure B-7.

Figure B-7. Site Installation Inspection report

Company Name

Site Installation Inspection Report

Project reference	
Link reference	
Site name	
Terminal name	
Remote site & terminal names	

Inspected by	
Signature	
Date	

Checked Item	**Pass**	**Fail***	**Comments**
Commissioning form complete & correct			
Antenna mounting			
Antenna side support (if used)			
ODU fastening			
ODU grounding			
IDU / ODU cable-connector weatherproofing			
IDU / ODU cable fastening			
IDU / ODU cable grounding			
IDU / ODU cable labelling			
Lightning surge suppressor(s)			
Protective grease/paint application			
IDU location in rack			
IDU labelling			
IDU grounding			
IDU power supply wiring			
Trib cable installation and labelling			
PSU and battery installation			
Alarms all-clear			
Site left clean and tidy			
Site photos taken			

* Use the Remedial Action Form to specify the corrective action required.

Additional Comments:

Acceptance Form

The Acceptance Form captures acceptance status following an installation inspection. Categories are provided for accepted, conditionally accepted, or not accepted.

Where conditionally accepted or not accepted, the Remedial Action Form should be filled out to capture the remedial work required.

The layout of the Acceptance Form is shown in Figure B-8.

Figure B-8. Acceptance Form

Company Name

Link Acceptance Form

Project reference	
Link reference	
Site names	
Terminal names	
Date	

Related documents	Received Yes/No
Link Installation and Commissioning Form:	
Site Installation Inspection Reports:	

Acceptance Category*	Category
Accepted / Conditionally Accepted / Not Accepted:	

*If conditionally accepted or not accepted, the action required to achieve acceptance must be detailed in a Remedial Action Form

Signed By:

Customer	
Name:	
Signature:	
Title:	
Date:	

Installer	
Name:	
Signature:	
Title:	
Date:	

Remedial Action Form

The Remedial Action Form captures the remedial action required on a new installation so that it can be accepted as a completed installation. Its layout is shown in Figure B-9.

Figure B-9. Remedial Action Form

Company Name

Site Remedial Action Form

Project reference	
Link reference	
Site name	
Terminal name	

Item No.	Remedial Action Required	Responsibility	Signed

Signed As Completed

Customer	
Name:	
Signature:	
Title:	
Date:	

Installer	
Name:	
Signature:	
Title:	
Date:	

Appendix C. Voltage Standing Wave Ratio (VSWR) Reference Chart

This appendix describes the relationship between VSWR, return loss, and power.

VSWR	Return Loss (dB)	Reflected Power (%)	Transmitted Power (%)	Transmission Loss (dB)
1.00	~	0.000	100.000	0.000
1.05	32.25	0.060	99.940	0.003
1.10	26.45	0.227	99.773	0.010
1.15	23.12	0.487	99.513	0.021
1.20	20.83	0.826	99.174	0.036
1.25	19.09	1.234	98.766	0.054
1.30	17.70	1.700	98.300	0.074
1.35	16.54	2.217	97.783	0.097
1.40	15.56	2.779	97.221	0.122
1.45	14.72	3.375	96.625	0.149
1.50	13.98	4.000	96.000	0.177
1.55	13.32	4.653	95.347	0.207
1.60	12.74	5.327	94.673	0.238
1.65	12.21	6.017	93.983	0.269
1.70	11.73	6.724	93.276	0.302
1.75	11.29	7.437	92.563	0.336

VSWR	Return Loss (dB)	Reflected Power (%)	Transmitted Power (%)	Transmission Loss (dB)
1.80	10.88	8.162	91.838	0.370
1.85	10.51	8.892	91.108	0.404
1.90	10.16	9.629	90.371	0.440
1.95	9.84	10.370	89.630	0.475
2.00	9.54	11.110	88.890	0.511
2.05	9.26	11.850	88.150	0.548
2.10	8.98	12.660	87.340	0.584
2.15	8.75	13.330	86.670	0.621
2.20	8.52	14.060	85.940	0.658
2.25	8.30	14.190	85.210	0.695
2.30	8.09	15.520	84.480	0.732
2.35	7.89	16.240	83.760	0.770
2.40	7.71	16.960	83.040	0.807
2.45	7.53	17.670	82.330	0.844
2.50	7.36	18.370	81.630	0.882
3.00	6.02	25.000	75.000	1.249
3.50	5.11	30.860	69.140	1.603
4.00	4.44	36.000	64.000	1.938
4.50	3.93	40.500	59.500	2.255
5.00	3.52	44.450	55.550	2.553

Appendix D. Typical Fault Scenarios

Table D-1 provides fault descriptions, probable causes, and recommended actions for a range of typical path related faults.

> General hardware and software fault alarms are not included as with few exceptions they are equipment specific.
>
> However, for a software alarm not related to any software update action or terminal reconfiguration, rebooting the terminal (power off > pause > power on) may be worth trying.

The scenarios assume you have typical NMS or craft tool access to performance and alarm events.

Table D-1. Typical Alarm Scenarios

Description	Probable Cause	Recommended Actions
Cannot establish management communications with a remote terminal(s).	Path loss or equipment malfunction.	• Check for other alarms. If there are traffic affecting path alarms the problem is most likely caused by a path failure. Check the NMS alarm history and events log screens for confirmation. • If there are no traffic affecting path alarms the probable cause is an NMS communications failure between the local and remote terminals, which is likely due to an equipment malfunction. Check for other equipment alarms to see if the failure can be narrowed down to a likely module failure. Check to see if the communications failure is a both-way or one-way problem. If both-way, the problem is more likely to be within the terminal controller. If one-way the problem is more likely to be within the mux (Tx) or demux (Rx) stages Loss of communications may also occur if incorrect IP addressing is set for one of the terminals.

Description	Probable Cause	Recommended Actions
The radio path is down. True for non-protected and for protected/ diversity configurations.	Path loss or equipment malfunction.	• Path loss can be caused by rain fade, diffraction or multipath/ ducting. Traffic will be affected in both directions. A complete path loss will almost invariably be preceded by RSL and BER alarms. Check NMS alarm history and events log screens for confirmation. • Equipment malfunction. An equipment related path loss should be signalled by hardware or in some cases software alarms. Such alarms may be at the local or remote end. To view remote end alarms will require a visit to that site (unless a network view is possible through the NMS).
Unable to switch to protected or diversity backup.	The transmit path or receive path switching criteria are met, but the configured alternative path is unavailable.	• Check for related alarms, which may indicate a standby unit is faulty. • Check the diagnostics alarms to see if a no-switch command has been forced.
Tx power alarm.	Faulty transmitter or faulty power measurement circuit.	• Check the Tx power setting and the power alarm thresholds. • Cross-check with the Tx power detected indication - if provided. • Check for related PA alarms, such as the PA current or Tx temperature alarms, which would indicate a PA fault. • A change in Tx power can be crosschecked by reference to the RSL at the remote end of the link. Check the history for a match. If there is no match (RSL normal) then the Tx power measurement/detection circuit is suspect.

Description	Probable Cause	Recommended Actions
Receive signal level is at or below alarm threshold.	Path conditions or equipment failure. The most common cause is path degradation through rain fade, diffraction or multipath.	• If a low RSL is indicated at **both ends** of the link, a path problem is indicated. Check the alarm history. If the RSL alarm is fleeting / not permanent and upon alarm clearance the RSL returns to its normal, commissioned level, rain, diffraction or mulipath fading is indicated. If such alarms are prevalent a problem with the link design or original installation is indicated. (Rain fade is the likely cause of fade for links 13 GHz and higher. Diffraction and multipath/ducting for links 11 GHz and lower). If the alarm is fleeting / not permanent but upon clearance the RSL never returns to its commissioned level, a change in the path or signal parameters is indicated, such as an antenna out of alignment, an antenna, feeder or connector problem or perhaps a newly constructed obstacle in the signal path. If the onset coincided with abnormal weather conditions such as exceptionally strong winds, suspect antenna alignment. • If the low RSL is at **just one end**, a hardware problem is indicated. Such problems are normally not fleeting, in which case the alarm history would show a permanent alarm with a definite commencement point. Check remote end Tx power and alarms. Check local end alarms, especially those associated with the demultiplexer/receiver/ODU.
G.826 errored seconds ratio exceeded.	Path conditions, interference or equipment malfunction.	• If an ESR alarm is indicated at both ends a path problem is indicated. Such errors should also show as RSL *and* BER alarms; check their alarm history and event log screens. • Interference normally affects just one end of a link. RSL will be unaffected but there will be related BER alarms. • A malfunction should be signalled by equipment alarms. Such alarms may be at the local or remote end and may be one-way or both-way traffic affecting.

Description	Probable Cause	Recommended Actions
Bit error rate alarm: 10^{-3} or 10^{-6}.	Path conditions, interference or equipment malfunction. The most common cause is path degradation through rain fade, diffraction or multipath.This alarm is raised at the affected end of the link only, though in a path fade situation usually both ends are similarly affected and hence both ends are alarmed.10^{-3} path errors will normally be preceded by 10^{-6} BER alarms.	• If the BER alarms coincide with low RSL and both ends of the link are similarly affected, a path problem is indicated. Check alarm history. If the BER alarm is fleeting / not permanent and upon alarm clearance the RSL returns to its normal, commissioned level, rain, diffraction or mulipath fading is indicated. If such alarms are prevalent a problem with the link design or original installation is indicated. (Rain fade is the likely cause of fade for links 13 GHz and higher. Diffraction and multipath/ducting for links 11 GHz and lower). If the alarm is fleeting / not permanent but upon clearance the RSL never returns to its commissioned level, a change in the path or signal parameters is indicated, such as an antenna out of alignment, an antenna, feeder or connector problem or perhaps a newly constructed obstacle in the signal path. If the onset coincided with abnormal weather conditions such as exceptionally strong winds, suspect antenna alignment. • If the BER alarms coincide with low RSL and just one end of the link is affected, an equipment problem is indicated. Such problems are normally not fleeting, in which case the alarm history would show a permanent alarm with a definite commencement point. Check remote end Tx Forward Power and alarms. Check local end alarms, especially those associated with the demux/receiver/ ODU. • If RSL appears normal and just one end of the link is affected then equipment or interference problems are indicated. An equipment problem is not normally fleeting, in which case the alarm history would show a permanent alarm with a definite commencement point. Check for related equipment alarms at both ends of the link. The problem could be at the remote transmitter or local receiver with, for example, a failure within the modulation or demodulation processes or a noisy local oscillator. Use loopback diagnostics to assist isolation. Investigating an interference problem should only be after all other link health indicators have been found to be normal. First check to see if there have been new link installations in the same geographical area and on the same frequency band, and which coincide with the onset of BER alarms. If interference is suspected, confirmation may require checks using a spectrum analyzer.

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